REFRACTION OF THE EYE

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INCLUDING

ELEMENTARY PHYSIOLOGICAL OPTICS

BY

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INTRODUCTION BY

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To

MY FATHER AND MOTHER

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INTRODUCTION

Clear vision in man depends upon the formation of well-defined images upon the retina. This is brought about by means of an optical apparatus resembling a photographic camera. The apparatus is subject to the ordinary laws of optics. It often shows aberrations and other defects, some of which are common to all optical instruments, others peculiar to the eye. It is evident that a thorough knowledge of the principles of optics underlying this fundamental apparatus of vision is essential to a sound study of the subject. Unfortunately, the mathematical aspect of physical facts appears to be peculiarly repulsive to minds which find their chief interest in biological affairs. Yet the mathematics necessary is neither large in amount nor transcendental in quality. It is rendered least unpalatable when served up in geometrical form.

Mr. Goulden has succeeded in this book in smoothing the path for the student without sacrificing accuracy of statement. He covers a wide field, which includes all the essentials which an ophthalmologist should know. It is to be hoped that the book will find favour, not only on its own account, but because it will tend to the improvement of the practice of ophthalmology in this country.

J. HERBERT PARSONS.

PREFACE

This book is the outcome of a series of lectures on Physiological Optics delivered periodically at the Royal London Ophthalmic Hospital to students preparing for the Diploma in Ophthalmic Medicine and Surgery of the Conjoint Board of England.

Its object is to provide students with an exposition of the elementary facts upon which the study of the refraction of the eye is based. It is not merely a handbook explaining the various clinical methods of examining the eye when correcting errors of refraction. Certain methods are explained which are in common use and which the author has found of service, but, for a description of the many other methods and apparatus, the reader is referred to one of several works in which details may be found.

The student should make himself familiar with a selected number of methods and apparatus, and then, by applying these assiduously in the out-patients' department of a hospital on many hundreds of cases of error of refraction, become skilful in their use. It is only in this way that any reliability can be placed on the spectacles prescribed. The establishment of diplomas in Ophthalmology has drawn attention to the importance of a sound basis in Physiological Optics for those who would correct errors of refraction otherwise than by rule of thumb, and has made the acquirement of the knowledge compulsory for those who enter for the examination.

A certain amount of mathematics is necessary, and in this book the geometrical method of exposition has been used as far as possible. The source of information has been set out in the bibliography, and the author would mention specially the "Lecture Notes on Light," by J. R. Eccles, on which many of the diagrams in Chapter I. have been based, and the lucid

articles on Ophthalmoscopy by Dr. Pacalin which appeared in the *Archives d'Ophtalmologie* in 1922 and 1923.

For students preparing for higher examinations the text-book on Ophthalmic Optics by Sir John Parsons and the section on the Eye in "Traité de Physiologie," by Morot and Doyon, are recommended. Very shortly the whole of the third edition of Helmholtz's "Physiological Optics" will be available in English; the first volume has already appeared.

The diagrams have been drawn by Miss Hilda Lomas, to whom the author wishes to express his thanks.

The plates of Figs. 178, 179, and 180 have been kindly lent by Messrs. C. W. Dixey, and the index has been prepared by Mr. A. L. Clarke.

Thanks are especially due to Dr. C. L. Harris for her help. She has read the whole of the manuscript and proofs, and has made many and valuable suggestions. She has also worked out all the problems and proofs in the mathematical portions of the book, so that it is hoped that they are free from serious error.

Messrs. J. & A. Churchill have been most patient and courteous, and have always acceded to any request that the author has made.

CHARLES GOULDEN.

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CHAPTER I

OPTICS

Light is the agent which, by its action on the retina, excites in us the sensation of vision.

If with a healthy eye there is absence of visual sensation, we infer the absence of light.

Certain objects are termed *self-luminous* when visible in the absence of all other sources of light, as, for example, the sun, a candle, a glow-worm, luminous paint that has been exposed to sunlight.

Most objects are *non-luminous*, and become visible by the light received from other objects and returned to our eyes.

Rectilinear Propagation of Light.—That light travels in straight lines can be shown in a variety of ways. Thus a small object held between the eye and a small source of light renders it invisible, by intercepting the light from the source which would otherwise have reached the eye.

The term *ray* is applied to the path along which light travels from each point of a luminous object.

A collection of rays is called a *pencil* of rays, which is usually in the form of a cone.

When light proceeds from a point, the pencil is termed *divergent*; when towards a point, *convergent*.

When rays converge towards or diverge from a point at an infinite distance, they form a *pencil of parallel rays*.

Shadows.—Let A be a small source of light, and B an opaque object. Since the rays from A are intercepted by B, and the

rays that pass B are not appreciably modified, there is an area extending from B which receives no light from the source A.

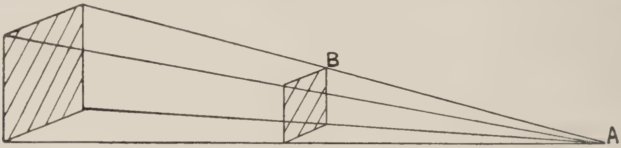


Fig. 1.

If a screen be held in this area, a shadow the same shape as B is cast, and if lines be drawn from A to the boundaries of B, they will cut the screen to form the boundaries of the shadow.

If the source of light be not small—and most luminous bodies

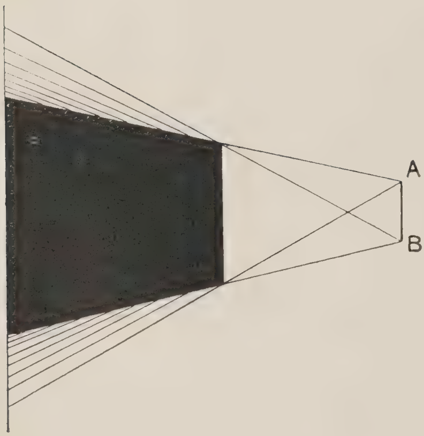


Fig. 2.—Opaque object somewhat larger than source of light.

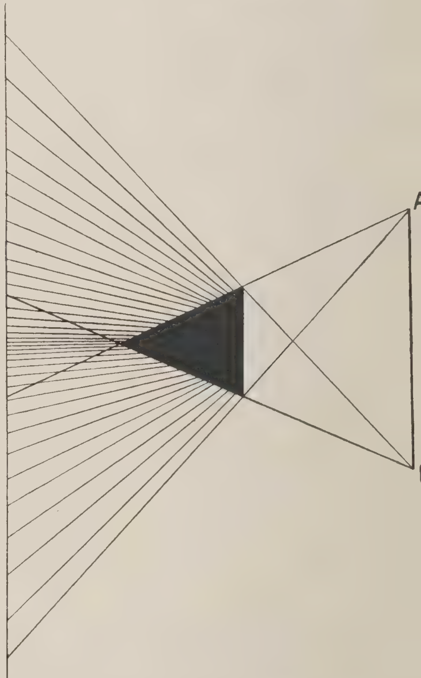


Fig. 3.—Source of light much larger than opaque object.

are of appreciable size—each point of the source throws a shadow cone, and it is only the area which is common to each

shadow cone which is entirely free from light. This conical space which receives no light is termed the *umbra*, whilst the surrounding area, which is only partially in shadow, is termed the *penumbra*.

Pinhole Camera.—Let AB be a luminous object, O a small aperture in an opaque screen, and CD a screen.

Rays of light diverge from any point of AB, such as A, and a certain very small pencil will pass through O, and on the screen

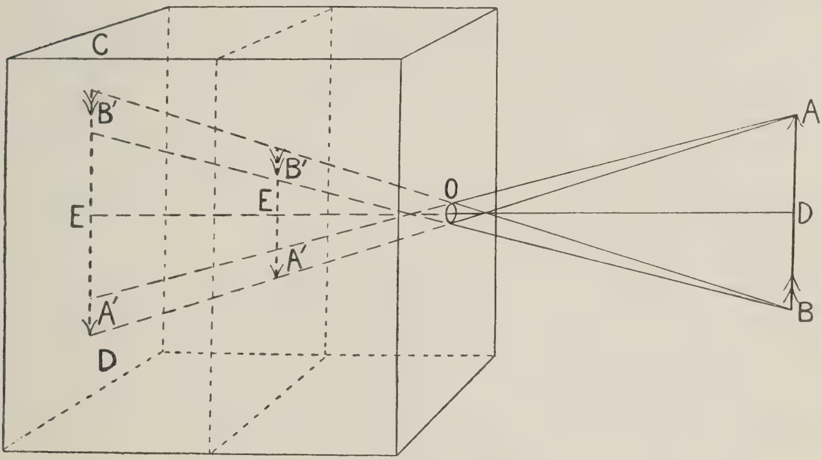


Fig. 4.

will be depicted a picture of the luminous point A. The same is true of each point of the luminous object AB. As the rays cross at the hole O, the picture of AB is inverted. By varying the position of the screen it can be shown, from the size and position of the picture, that the path of each ray is straight.

Again, if $\mathrm{DO} = u$ and $\mathrm{OE} = v$,

then $$\frac{\mathrm{A'B'}}{\mathrm{AB}} = \frac{v}{u}$$

By increasing v or reducing u within certain limits, the image A′B′ can be made larger, but, since by decreasing u the pencil of rays from a point of the object AB become more divergent, the image is blurred.

If several small apertures be made in the screen, as many images of AB are formed on the screen at the back of the camera. When these images overlap, the outlines become blurred, and when the number of holes is sufficient we have uniform illumination of the screen, which may be looked upon as arising from innumerable overlapping images.

The form of the image is independent of the shape of the aperture, which merely influences the shape of the individual light spots on the screen.

A substance through which light can be transmitted is spoken of as an *optical medium*, which, when it has identical properties at all points, is called *homogeneous*, and when it has different properties at different points is called *heterogeneous*.

Substances are roughly divided into *transparent*, or, those through which light can pass, and *opaque*, those which intercept it. Opaque objects are said to *absorb* light.

Law of Inverse Square.—The intensity of illumination at a point at a given distance from a small source of light is inversely proportional to the square of the distance of the point from the source.

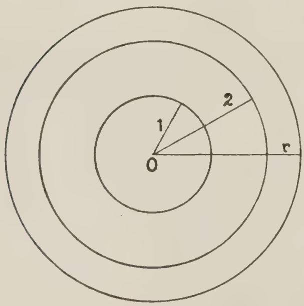


Fig. 5.

Let O be a source emitting light equally in all directions. With O as a centre, describe a series of spherical surfaces with radii of 1, 2 . . . r centimetres.

Let $L_1, L_2 \ldots L_r$ be the amounts of light falling per second on unit area of each sphere. The areas of the spheres are :

$$4\pi,\ 4\pi \times 2^2 \ \ldots\ 4\pi \times r^2.$$

The total quantity of light falling per second on each sphere is :

$$4\pi L_1,\ 4\pi 2^2 L_2 \ \ldots\ 4\pi r^2 L_r,$$

and these are all equal.

$$\therefore \qquad 4\pi r^2 L_r = 4\pi L_1,$$

i.e.,
$$L_r = \frac{L_1}{r^2}.$$

Reflection of Light.—When a ray of light falls on a smooth surface, part of the incident light is reflected according to certain laws.

Laws of Reflection.—1. The incident ray, the normal to the surface at the point of incidence, and the reflected ray lie in one plane.

2. The incident and reflected rays are equally inclined to the normal, and lie on opposite sides of it.

That is, the angle of incidence is equal to the angle of reflection.

Plane Mirrors.—*Formation of the Image.*—Let P be any point on a ray PR incident at R on the surface AB. Draw

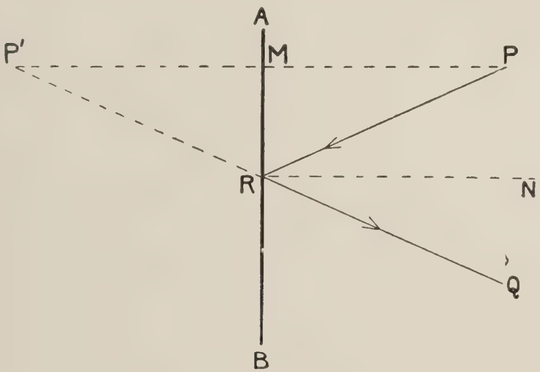


FIG. 6.

PM perpendicular to the surface and produce it to P′, making MP = MP′. Let PR be any incident ray. Join P′R and produce it to Q. Then RQ shall be the reflected ray. Draw RN normal to the surface at R.

By construction PR, RQ, and RN are in one plane.

In the two triangles RPM, RP′M

$$PM = MP', \text{ and } MR \text{ is common,}$$
$$\angle PMR = \angle P'MR,$$

therefore these triangles are equal in all respects and the

$$\angle \mathrm{RPM} = \angle \mathrm{RP'M}.$$

Since RN is parallel to MP,

$$\angle \mathrm{NRP} = \angle \mathrm{RPM},$$

and $$\angle \mathrm{NRQ} = \angle \mathrm{RP'M}.$$

$\therefore$ $$\angle \mathrm{NRQ} = \angle \mathrm{NRP}.$$

Since RQ is in the same plane as the incident ray and the normal, and makes with the normal an angle equal to the angle of incidence, therefore RQ is the reflected ray.

Now PR is any incident ray ; hence the reflected ray corresponds to any incident ray that passes through P′.

$\therefore$ All reflected rays pass through P′ ; and P′ is the image of P.

The image of an object in front of a plane mirror is situated at the same distance behind the mirror that the object is in front of it, and is equal in size to the object.

It will be seen, when considering curved mirrors, that the same construction applies, if AB represents the tangent plane at the point R on the curve.

Images may be either real or virtual.

1. When a pencil of rays diverging from a point, after reflection or refraction, *appears to diverge from* a second point, the second point is called the virtual image of the first point.

Such an image is produced by a plane mirror.

2. When a pencil of rays diverging from a point, after reflection or refraction, *converges* to a second point, the second point is called the real image of the first point.

To prove that, when a mirror is turned through any angle, the reflected ray is turned through twice that angle.

1. When the incident ray is perpendicular to the mirror.

Let a = angle through which mirror is turned.

The angle through which the reflected ray is turned

$$\begin{aligned} &= \mathrm{ABC} \\ &= 2\mathrm{ABN} \\ &= 2a. \end{aligned}$$

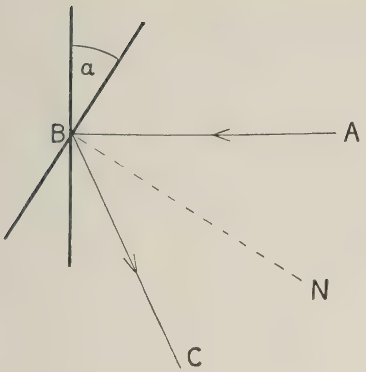


Fig. 7.

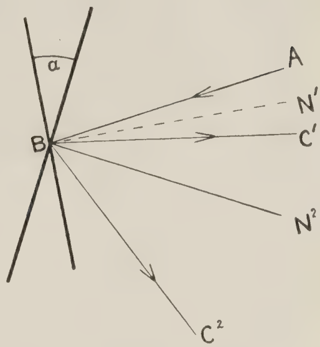


Fig. 8.

2. When the incident ray is not perpendicular to the mirror. The angle through which the reflected ray is turned

$$
\begin{aligned}
&= C_1BC_2 \\
&= ABC_2 - ABC_1 \\
&= 2ABN_2 - 2ABN_1 \\
&= 2(ABN_2 - ABN_1) \\
&= 2N_1BN_2 \\
&= 2a.
\end{aligned}
$$

Spherical Mirrors.—A polished surface having the form of a portion of a sphere is called a *spherical mirror*. The centre of the sphere of which the mirror forms part is called the *centre of curvature* of the mirror.

A spherical mirror is either concave or convex, according as the polished surface faces towards or away from the centre of curvature.

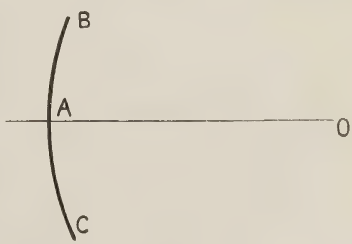


Fig. 9.

The middle point of the surface of the mirror is called the *pole* or *vertex* of the mirror.

The line joining the centre of the sphere to the middle point of the surface of the mirror is known as the *axis of the mirror.*

O = centre of curvature of the mirror BAC.
A = pole or vertex of the mirror.
OA = axis of the mirror.

In our considerations of spherical mirrors we shall suppose that the source of light is not far from the axis of the mirror, so that the axis of a pencil of rays from the source of light falls on the mirror very near to A. In these circumstances the axis of the pencil of rays is inclined at only a small angle to the axis of the mirror, and the incidence is very nearly *direct*.

If a small pencil of parallel rays, parallel to the axis of the mirror, is incident directly on a mirror, the rays, after reflection, either converge to or appear to diverge from a point on the axis known as the *principal focus* of the mirror (Fig. 10).

The distance from the principal focus of a mirror to its pole is known as the *focal length* of the mirror.

A pencil of rays diverging from a point on the axis of a mirror, after reflection, converges to or appears to diverge from a second point on the axis. This second point is the *geometrical image* of the first point.

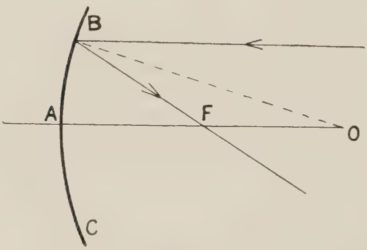


Fig. 10.

A point and its geometrical image are spoken of as *conjugate foci*.

Geometrical Conventions as to Signs.—The specification of a distance involves three elements: (*a*) a numerical magnitude, in inches, centimetres, and so on; (*b*) a direction; and (*c*) a point from which a measurement is taken.

When we wish to define the position of a point on the axis of a mirror we make use of the following convention:

Distances are measured along the axis of a mirror from a point A, the pole of the mirror (Fig. 11).

When measured in a direction opposite to that in which the incident light travels, that is, to the right, the distance is

positive; when measured in the opposite direction, that is, to the left, negative.

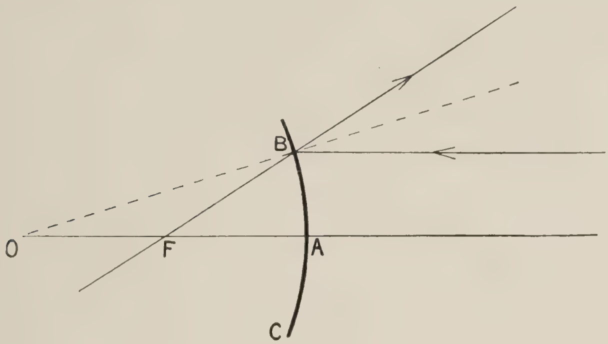


Fig. 11.

O $=$ centre of curvature of the mirror,
OA $= r =$ radius of curvature,
F $=$ the principal focus,
and AF $= f =$ focal length.

In the concave mirror:

$$AO = r,$$
$$AF = f.$$

In the convex mirror:

$$AO = -r,$$
$$AF = -f.$$

The laws of reflection as laid down when dealing with plane mirrors apply equally when dealing with spherical mirrors. If we take a very small portion of the spherical surface, it is practically a plane surface, but the normal to the surface differs in direction with each portion of the spherical surface so considered.

Reflection of a Small Pencil at a Concave Spherical Surface.—Let P be a luminous point, the focus of a small pencil incident upon BAC, a concave spherical mirror.

Let POA be the axis of the mirror.

Let PB be any incident ray which, after reflection, cuts the axis in Q.

Let
$$PA = u,$$
$$QA = v,$$
$$OA = r,$$
the radius of curvature of the mirror.

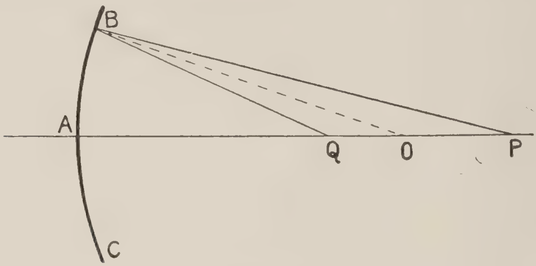


FIG. 12.

The angle QBO = angle PBO.

Then in the triangle PBO, QBO

$$PB : BQ :: PO : QO.$$

Now PB is practically equal to PA, since the pencil is very small ; and, also, QB is practically equal to QA.

Therefore
$$PA : QA :: PO : QO$$
$$u : v :: u - r : r - v$$
$$u(r - v) = v(u - r)$$
$$ur - uv = uv - vr.$$

Divide by uvr.

Then
$$\frac{1}{u} + \frac{1}{v} = \frac{2}{r}.$$

This formula shows that all rays from P on the axis of the mirror meet in Q, which is also on the axis.

The points P and Q are, therefore, conjugate foci.

Principal Focus.—If the incident rays of the pencil are parallel, then $u = \infty$.

Then
$$\frac{1}{\infty} + \frac{1}{v} = \frac{2}{r},$$

and
$$v = \frac{r}{2} = f.$$

That is, parallel rays are brought to a focus in the middle point of AO, the principal focus F of the mirror.

That is, the focal length of the mirror, f, is half the radius of curvature.

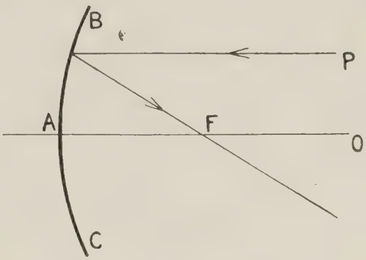


FIG. 13.

To Construct the Image formed by a Spherical Surface.—In determining the position of an image we need only trace two reflected rays, since at the point where two rays intersect there will be the image required.

We usually select the ray reflected from a ray parallel to the axis, and therefore passing through the principal focus, and another directly incident upon the mirror, which necessarily passes through the centre of the mirror, and so will be reflected along the path of incidence.

Concave Mirror.—Let A be the centre of surface of the mirror, F the principal focus, O the centre of the mirror, OFA the axis.

Let P be a luminous point near to the axis, and PQ perpendicular to the axis. PQ may then be considered a small object.

Let us make use of the parallel ray PR, and the ray PT which falls on the mirror normally. The ray PR will be reflected through the principal focus, and the ray PT will be reflected directly back.

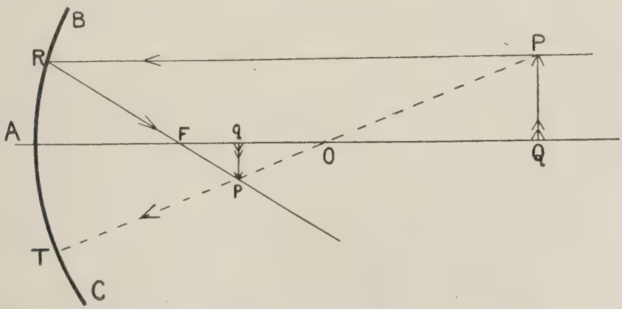


FIG. 14.

1. Let the object be placed beyond the centre of curvature of the mirror.

If the object be placed at infinity, the image will be formed at the principal focus.

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{f} - \frac{1}{\infty}.$$

$$\therefore \qquad \frac{1}{v} = \frac{1}{f}.$$

Thus $$v = f.$$

2. As the object moves along the axis towards the mirror the

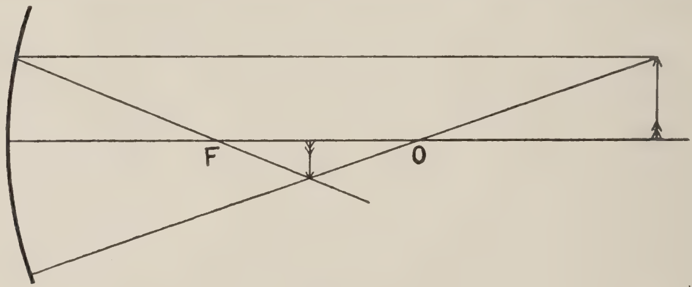


Fig. 15.

value of u diminishes, and so $\frac{1}{u}$ increases, with the result that $\frac{1}{v}$ diminishes and v increases. The image, therefore, moves from the mirror along the optic axis.

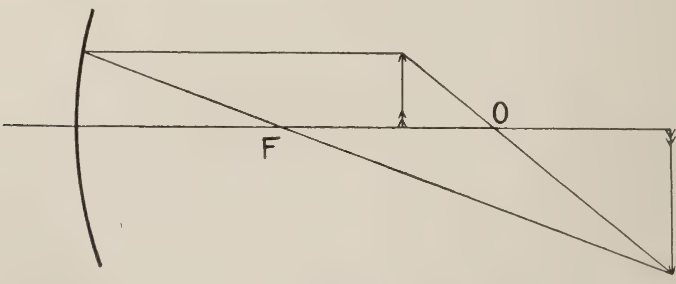


Fig. 16.

3. When the object is at O, then $u = r$, that is, the image is formed at the same point as the object.

4. When the object lies between O and F, the value of v is greater than r, and it lies between r and ∞.

5. When the object is at F, then $u = f$, and $v = \infty$, so that the image is formed at infinity.

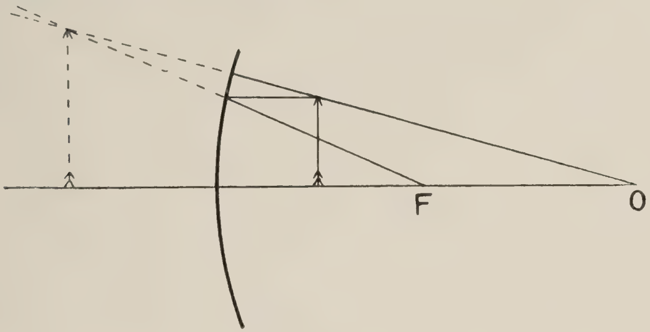


Fig. 17.

6. When the object is nearer to the mirror than F, u is less than f, and therefore $\frac{1}{u}$ is greater than $\frac{1}{f}$. Then v must be negative, so that the image is virtual, being formed on the negative side of the mirror (Fig. 17).

Convex Mirror.—In spherical convex mirrors the reflection

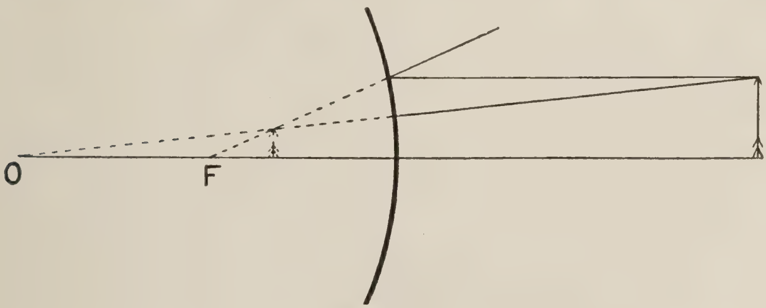


Fig. 18.

takes place on the outside of the curved surface of a section of a sphere.

Rays which fall parallel to the axis on a convex mirror diverge after reflexion as if they proceeded from a point F, the principal

focus of the mirror, which, as we have seen, is half the length of the radius behind the mirror. Conversely, a cone of rays converging to this point is reflected as a parallel beam.

Choosing a ray parallel to the axis, and another ray normal to the surface, we are able to construct an image of an object in the same manner as with a concave mirror. The image, however, is a virtual, erect image, behind the mirror, and since the two rays chosen are always convergent in direction, the image is always diminished in size (see p. 41).

Refraction.—When a ray of light travelling in one medium falls obliquely on the surface of another medium, part of the ray passes into the medium, but in so doing is bent or refracted so that the new direction differs from the old. We have thus to deal with an *incident ray* and a *refracted ray.*

If the second medium is denser than the first, the angle that the refracted ray makes with the normal to the bounding surface is smaller than that between the incident ray and the normal to the surface; conversely, if the second medium is less dense, then the angle between the refracted ray and the normal is greater than that between the incident ray and the normal.

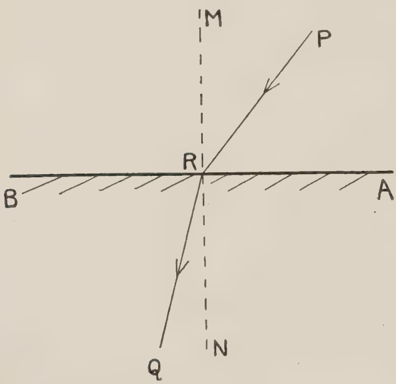


Fig. 19.

Let PR be an incident ray lying in the plane of the paper. Let this ray meet the surface AB separating different media, such as air, above, and a denser medium, water or glass, below. The surface AB is thus perpendicular to the paper, and the normal MN in the plane of the paper. Let RQ be the refracted ray, which is also in the plane of the paper. The angle PRM between the incident ray and the normal in air is greater than the angle QRN between the refracted ray and the normal in water.

Laws of Refraction.—1. The incident ray, the normal to the surface at the point of incidence, and the refracted ray lie in one plane.

2. The sine of the angle between the incident ray and the normal bears to the sine of the angle between the refracted ray and the normal a ratio which depends only on the two media and on the nature of the light.

If ϕ be the angle of incidence and ϕ' the angle of refraction, then by the second law

$$\frac{\sin \phi}{\sin \phi'} = \text{a constant}$$

which may be expressed by μ, and $\sin \phi = \mu \sin \phi'$.

Thus μ is the *refractive index* of the medium, and to find the refractive index we must know the ratio that the sine of the angle of incidence bears to the sine of the angle of refraction.

If the first medium is a vacuum or air (which is practically the same), this ratio is called the *absolute index of refraction*; in other cases it is the *relative refractive index* of the two media.

This law, discovered by experiment, is corroborated by a consideration of the wave theory of light, where it is found that the refractive index of a medium is inversely proportional to the velocity of light in that medium.

Thus the index of refraction $\mu = \frac{v_1}{v_2}$, the ratio of the velocities of light in the first and second medium.

If we are considering light travelling from air to glass, then refractive index from air to glass

$$= \frac{\text{velocity of light in air}}{\text{velocity of light in glass}}.$$

If we consider light travelling from glass to air, ϕ' becomes the angle of incidence in glass, and ϕ the angle of refraction in air; then $\sin \phi = \mu \sin \phi'$, and $\sin \phi' = \frac{1}{\mu} \sin \phi$, and so $\frac{1}{\mu}$ is the refractive index from glass to air.

Thus the index of refraction from medium A to medium B is the reciprocal of the index of refraction from medium B to medium A.

Total Reflection.—When a ray passes from a medium of less density to one of greater density, then the angle of refraction is less than the angle of incidence; consequently, when a ray passes from a medium of greater density into one of lesser density, then the angle of refraction is greater than the angle of incidence.

As the angle of incidence is increased the emergent ray makes a smaller and smaller angle with the surface of the medium.

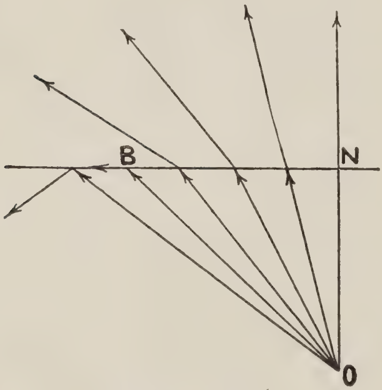


FIG. 20.

If a ray is travelling in any medium in such a direction that the emergent ray just grazes the surface of the medium, the angle which is made with the normal is called the "critical angle."

If the ray makes with the normal a greater angle than the critical angle, all light travelling in the direction of the ray is totally reflected.

$$\mu = \frac{\text{sin angle of incidence}}{\text{sin angle of refraction}}$$

$$= \frac{\text{sin critical angle}}{\sin 90^\circ}$$

$$= \frac{\text{sin critical angle}}{1}$$

$$\therefore \qquad \text{sin critical angle} = \mu.$$

This, then, gives us a method of determining the index of refraction of a substance if we find experimentally the critical angle.

If the angle of incidence be very small, by so much the smaller is the angle of refraction, and then the arcs which correspond to these angles do not differ materially from the sines, so that

$$\phi = \mu\phi'.$$

That is, when the incidence is nearly perpendicular the angle of incidence is μ times the corresponding angle of refraction.

Refraction through a Parallel Plate.—Let there be a plate of

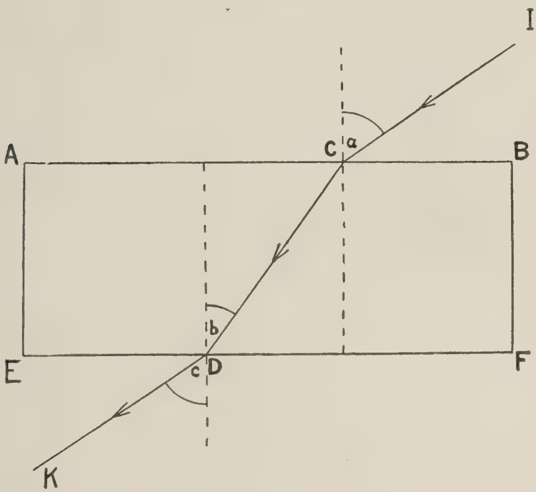


Fig. 21.

glass, ABEF, surrounded by air, and let ICDK be an incident refracted and emergent ray.

$$\frac{\sin a}{\sin b} = \mathrm{A}\mu\mathrm{G}$$

$$\frac{\sin c}{\sin b} = \mathrm{A}\mu\mathrm{G}$$

$$\therefore \quad \frac{\sin a}{\sin c} = 1$$

$$\therefore \quad \sin a = \sin c$$

$$\therefore \quad a = c.$$

That is, the emergent ray is parallel in direction to the incident ray.

Prisms.—A prism is a medium bounded by two plane surfaces meeting in an edge, and the angle that these two surfaces make is called the apical or refracting angle ; that part of the prism opposite the angle is called the base.

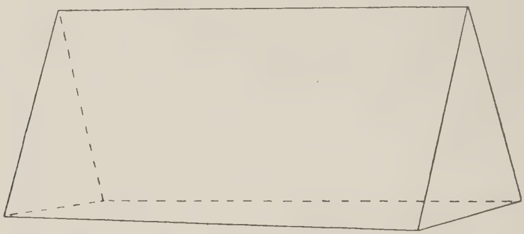


Fig. 22.

In a square prism the edge is the thinnest part ; the base is immediately opposite, and the shortest line joining the apex and base, which bisects the apical angle, is termed the base apex line.

If a square lens has been cut down to a circular or oval shape, such as is seen in cases of test lenses and spectacles, the base apex line is that which passes through the centre of the lens at right angles to the tangents to the thinnest and thickest part of the prism.

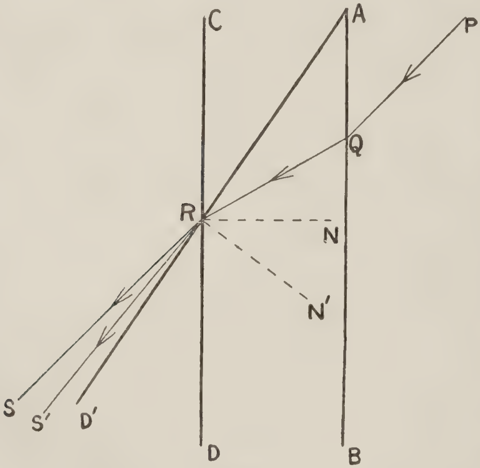


Fig. 23.

Prisms have several qualities, but since in ophthalmology only prisms with acute angles are used, the property they possess of altering the direction of incident rays of light is the only one we need consider (Fig. 23).

We have seen that the effect produced upon incident rays of light by a plane lamina is merely to cause a displacement of the direction of the rays to one side, so that the emergent rays are parallel to the incident rays, that is, PQ is parallel to RS.

If we imagine the side CD rotated about R, so that C meets A, a prism is produced and the angle of incidence at R is increased; consequently the deviation of RS must also be increased, and

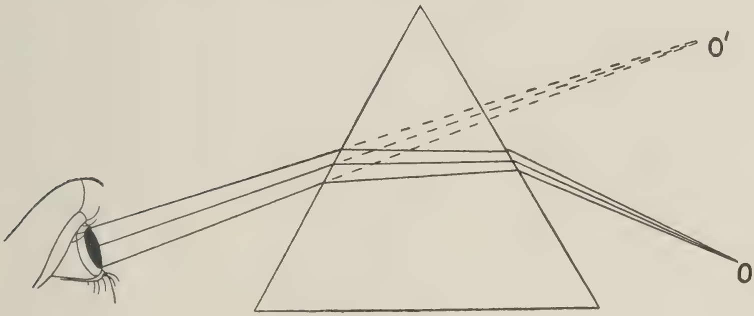


Fig. 24.

its new direction will be RS′; hence a prism deviates rays of light towards its base.

To the eye placed on the opposite side of a prism an object appears displaced towards the apex, since the rays will be projected backwards through the prism in the direction from which they appear to the eye to diverge.

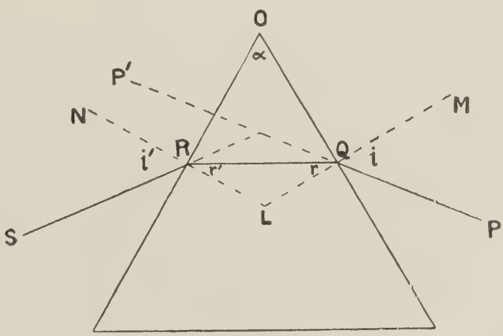


Fig. 25.

Let PQRS be a ray passing through a prism whose *refracting angle* is α, that is, the angle at which its refracting surfaces are inclined.

Let RN and QM be the normals to the surfaces at R and Q.

Let the angle of incidence PQM be i, and the angle of refraction LQR be r. Let LRQ be r', and NRS be i'.

By Snell's law

$$\sin i = \mu \sin r$$
$$\sin i' = \mu \sin r'.$$

The angle ORQ $= 90° - r'$.

The angle OQR $= 90° - r$.

Now the sum of the three angles of a triangle is 180° ; consequently

$$\alpha + (90° - r) + (90° - r') = 180°,$$

that is, $r + r' = \alpha$.

If the ray PQ had not been deviated by meeting the prism at Q, it would have continued its path to P′, so that the deviation at the first face is represented by

$$i - r$$

and at the second by

$$i' - r'$$

the total deviation being

$$\begin{aligned} D &= (i - r) + (i' - r') \\ &= i + i' - (r + r') \\ &= i + i' - \alpha. \end{aligned}$$

That is, the deviation produced by a prism is equal to the sum of the angles of incidence and emergence minus the refracting angle of the prism.

When the angles of incidence and emergence are equal, the ray is said to pass symmetrically through the prism.

The angle of incidence is greater than the angle of refraction, and the angle of refraction increases as the angle of incidence increases ; consequently, in the triangle LRQ, as the angle at L is constant, the angle r' must decrease in size, and since r increases less rapidly than i, i' must decrease more rapidly than r'. Therefore, an increase in the angle of incidence causes an increase in the angle of deviation at the first face, and a decrease at the second, and as r is greater than r', the increase at the first face is greater than the decrease at the second, and so the total deviation is increased. Again, if we decrease the angle at the first face, we increase the angle at the second face.

It is, therefore, the symmetrical ray which undergoes least deviation, and this ray is called the *ray of minimum deviation.*

In ophthalmology we assume that rays of light strike the prism symmetrically, and when we discuss prisms we allude to the deviation produced when rays strike them symmetrically.

In minimum deviation

$$i = i'$$

$\therefore$ $$\alpha = 2r$$

since $$\mathrm{D} = 2i - 2r$$
$$= 2i - \alpha.$$

We have seen that

$$\sin i = \mu \sin r,$$

and since the angles are very small we may say :

$$i = \mu r$$

$\therefore$ $$\mathrm{D} = 2\mu r - \alpha$$

since $$\alpha = 2r$$

$$\mathrm{D} = \mu\alpha - \alpha$$
$$= \alpha(\mu - 1)$$

The index of refraction of glass used in making prisms is

$$1{\cdot}5 = \frac{3}{2} = \mu$$

$\therefore$ $$\mathrm{D} = \frac{\alpha}{2}.$$

That is, the deviation produced by a glass prism with a *small* refracting angle is equal to half its refracting angle.

This rule holds for ophthalmic prisms where the refracting angle is small, and when the ray passes symmetrically through the prism.

Rotating Prisms.—If we take two prisms of equal strength and place them together so that the apex of one is against the base of the other, the result will be a thick plate of glass. If now they are rotated in opposite directions, they produce the effect of a single prism, gradually increasing until, when they are apex to apex, their effect reaches its maximum, both in deviating power and dispersion of light. Such a combination

of prisms is used in the apparatus for testing the power of the eyes to overcome diplopia in various directions.

The two prisms need not be placed before one eye only, but one may be placed before one eye and the other prism before the fellow eye, and the rotation effected whilst in this position. The advantage is that the distortion is equally distributed between the two eyes and, also, the chromatic dispersion is less.

The nomenclature of prisms is of great importance, since in prescribing prisms it is necessary to indicate what is meant by the figures and signs we use.

1. A very usual method, although less frequently used now, is that found in many trial cases, and it is the geometrical measure of the inclination of the two refractive sides ; in other words, the measure in degrees of the *apical angle*.

This method corresponds to the old method of marking lenses, in which the radius of curvature of the surfaces was indicated. It is one that has little to commend it, as, naturally, the effect of the lens depends not only upon the curvature of its surfaces, but also upon the index of refraction of the glass used in its manufacture, and, in the same way, the effectivity of the prism depends upon its apical angle and the index of refraction of the glass. We would, therefore, need to indicate upon the prescription not only the apical angle of the prism, but also the refractive index of the glass we wished to be used.

2. We prescribe prisms for the effect they produce upon rays of light, so the method of marking prisms by the *angle of minimum deviation* is an excellent one. If, therefore, on a prescription we write $4^\circ\ d$, the optician understands that the prism to be used must give this effect to rays of light, and it matters not what is the apical angle or the index of refraction of the glass, provided this effect is produced.

3. There are two other methods in use which have as their unit the deviation of 1 cm. at a distance of 1 metre. Maddox has named this the *centune* system, the *arc centune* being the angle subtended at 1 metre by 1 cm. of arc, the *tangent centune* the angle subtended by a vertical line 1 cm. in length at 1 metre distance.

(*a*) *Prism Dioptre or Tangent Centune.*—This measure is

designated by Δ, and therefore 1 Δ is an angle whose tangent is ·01 or 34·37643′, but 10 Δ is 5° 42·6355′, which is not ten times the value of 1 Δ.

It has the advantage of indicating at once the amount of decentering in a lens to produce the prismatic effect required, so that a 3 D lens decentered 1 cm. will give the effect of 3 Δ, and so on.

It will be seen in speaking of lenses that a convex lens may be considered as two prisms placed base to base, and a concave lens as two prisms placed apex to apex. The result, therefore, of decentering a lens is to bring before the eye a prism, but decentering a convex or concave lens inwards will have the effect of bringing a prism base in in one case, and base out in the other.

As the decentering of lenses has a very limited application—for instance, to decenter a spectacle lens 2 cm. an enormous original lens would be needed—and as spherical aberration rapidly produces effects as the periphery of the lens is reached, the simplicity of calculation in deciding the amount of decentering necessary in a particular lens to produce a required prismatic effect does not overcome its other disadvantages.

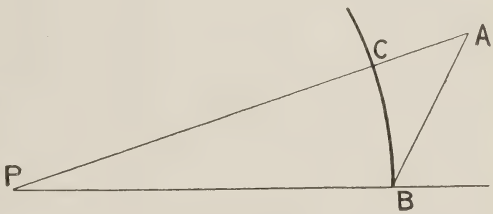


Fig. 26.

(*b*) *The Centrad or Arc Centune.*—Take a line AB and from a point P draw PA, PB; the line AB is said to subtend the angle APB at the point P.

With P as a centre, draw a number of arcs of different radii between AB and BP; then all these arcs subtend the same angle at P, and the ratio $\frac{\text{arc}}{\text{radius}}$ is the same whatever the arc chosen, and if the angle APB be θ, then $\frac{\text{arc}}{\text{radius}} = \theta$.

θ is called the circular measure of the angle APB, and the

unit of circular measure is the *radian*, which is the measure of an angle subtended by an arc equal in length to the radius.

A radian is 57° 29·578′.

The centrad is one-hundredth of a radian, that is, 34·37747′, and it is denoted by ∇, and is, therefore, the strength of prism that produces a deviation of 1 cm. of arc at a distance of 1 metre.

It has the great advantage that 10 ∇ is equal to ten times the value of 1 ∇.

Refraction at Spherical Surfaces.—The laws of refraction may be applied to a pencil of rays incident on a spherical refracting surface in a similar way to that employed when applying the laws of reflection to spherical surfaces.

Many of the terms employed there apply equally to cases of refraction, such as Principal Focus, Focal Length, Conjugate Focus, and so on.

Refraction at a Convex Surface.—Let APB be a curved surface separating a medium on the right with refractive index equal to 1 and a medium on the left with refractive index equal to μ.

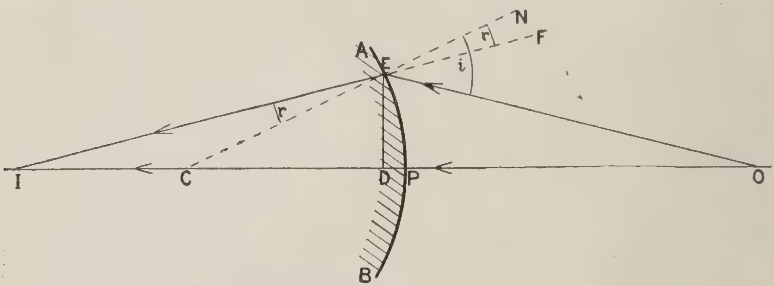


FIG. 27.

Let C be the centre of curvature, and OPC the principal axis.

Let OE be an incident ray, and CEN a radius through E, and therefore a normal to the surface APB at E.

Let EI be the refracted ray, and produce EI to F.

Let $\angle$OEN $= i$, the $\angle$IEC $=$ FEN $= r$.

Then $i = \mu r$, $\angle \mathrm{OEF} = (i - r) = (\mu - 1)r$,
$\angle \mathrm{EOP} = \mathrm{O}$, $\angle \mathrm{ECP} = \mathrm{C}$, $\angle \mathrm{EIP} = \mathrm{I}$,
$\angle \mathrm{OEN} = \angle \mathrm{ECP} + \angle \mathrm{EOP} \ldots \mu r = \mathrm{C} + \mathrm{O} \quad . \quad . \quad (1)$
$\angle \mathrm{OEF} = \angle \mathrm{EIP} + \angle \mathrm{EOP} \ldots (\mu - 1)r = \mathrm{I} + \mathrm{O} \quad . \quad (2)$

Multiply (1) by $(\mu - 1)$,
and (2) by (μ), and subtract.

Then
$$\mu\mathrm{I} - (\mu - 1)\mathrm{C} + \mathrm{O} = o.$$
$$\therefore \quad \mu\mathrm{I} + \mathrm{O} = (\mu - 1)\mathrm{C}.$$

Draw DE perpendicular to the optic axis, and let $\mathrm{DE} = y$.

As the angles O, I, and C are small, they may be represented by their tangents.

Then
$$\mathrm{DO} \risingdotseq \mathrm{PO} = u.$$
$$\mathrm{DI} \risingdotseq \mathrm{PI} = v.$$
$$\mathrm{DC} \risingdotseq \mathrm{PC} = r.$$

Then
$$\mathrm{I} = -\frac{y}{v}, \ \mathrm{C} = -\frac{y}{r}, \ \mathrm{O} = \frac{y}{u},$$

and
$$\frac{-\mu y}{v} + \frac{y}{u} = \frac{-(\mu - 1)y}{r}.$$

That is,
$$\frac{\mu}{v} - \frac{1}{u} = \frac{\mu - 1}{r}.$$

When u is infinity, $\frac{1}{u} =$ zero, and v must be equal to f, the focal length.

$$f = \frac{\mu r}{\mu - 1}.$$

When light is refracted from a medium of refractive index μ_1 to one of refractive index μ_2, we have seen that we must substitute μ by $\frac{\mu_2}{\mu_1}$.

So that
$$\mathrm{F}' = \frac{\mu_1 r}{\mu_2 - \mu_1}$$
$$\mathrm{F}'' = \frac{\mu_2 r}{\mu_2 - \mu_1},$$

which gives us the formula for calculating the anterior and posterior focal distances of the cornea.

Lenses.—A lens is a portion of any transparent medium bounded by surfaces that are parts of spheres.

There are two principal classes of lenses :

Fig. 28.

Fig. 29.

1. Convex or converging.
   (*a*) Double convex.
   (*b*) Plano convex.
   (*c*) Concavo - convex or convex meniscus.
2. Concave or diverging.
   (*a*) Double concave.
   (*b*) Plano concave.
   (*c*) Convexo-concave or concave meniscus.

The line joining the centres of the two spheres which bound the lens is called the *principal axis of the lens.*

A convex lens may be considered as a collection of prisms having their bases towards the principal axis of the lens (Fig. 30).

A concave lens may be considered as a collection of prisms having their bases directed away from the principal axis of the lens (Fig. 31).

Thus we see that a convex lens causes rays to *converge* to a point on the principal axis, whereas a concave lens causes rays to *appear to diverge* from a point on the principal axis.

In the case of parallel rays this point is spoken of as the *principal focus* of the lens.

The distance between a lens and its principal focus is called the *focal length* of the lens.

The reciprocal of the focal length of a lens is termed the power, or dioptric strength, of the lens.

The unit of power of a lens used in ophthalmology is spoken

of as a *dioptre* (D), which is a lens of 1 metre focal length. Convergent lenses are positive (and have the sign +), whereas divergent lenses are negative (with the sign —). Thus, to find the power in dioptres of a given lens, express the focal length

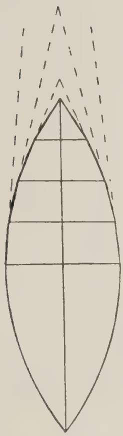


Fig. 30.

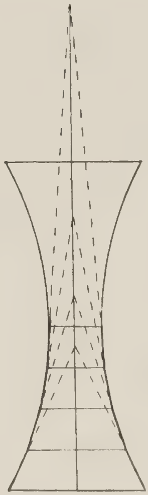


Fig. 31.

in terms of a metre, obtain its reciprocal, and change the sign of the result.

Thus, given a concave lens of 50 cm. or half a metre focal length, the reciprocal is 2, and, changing the sign, we have —2 dioptres as the power of the lens.

Optical Centre of a Lens.—Let R, S be two points on the lens at which the faces may be considered to be parallel.

Join these two points, and let the line joining them cut the axis AA′ in the point C. This point is called the *optical centre of the lens*.

Draw RO, SO′, normals at R and S, passing through O and O′, the centres of curvature of the faces, and let R^1, R^2 be the radii of the spherical surfaces.

Then RO and SO′ are parallel.

The triangles ORC, O′SC are similar.

Therefore $$\frac{OC}{O'C} = \frac{OR}{O'S} = \frac{OA}{O'A'}.$$

Hence $$\frac{AC}{A'C} = \frac{OA}{O'A'} = \frac{R^1}{R^2},$$

i.e., the point C divides OO′ in a definite ratio depending only upon the radii of the two spherical surfaces.

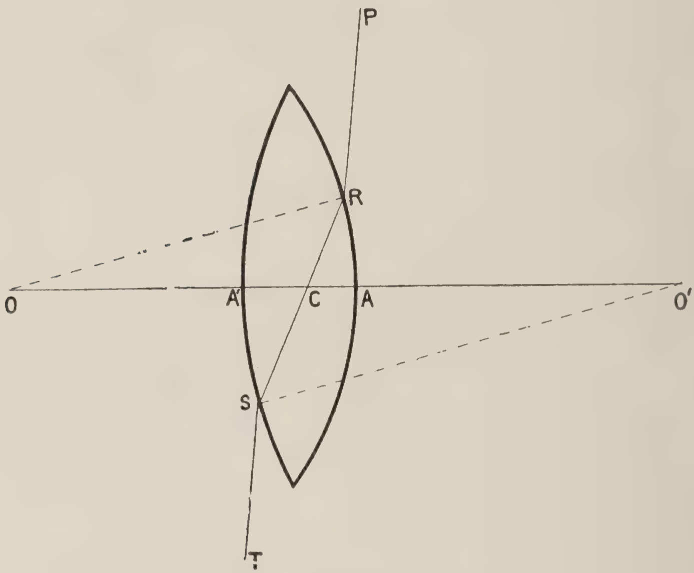


FIG. 32.

Since the angles between RS and the normals at R and S are equal, the angles between these same normals and the incident and emergent rays at R and S are also equal; and as the normals at R and S are parallel, then the incident and emergent rays at R and S are parallel.

Therefore, if a ray be incident on a lens in such a direction that the refracted ray in the lens passes through the optical centre, the emergent ray is parallel to the incident ray.

If, therefore, the incident and emergent rays are parallel, the

path of the ray in the lens intersects the axis in a fixed point, which is called the optical centre of the lens.

The lenses with which we deal in ophthalmology are very thin compared with their focal length, and so the points A and A′ are very near together, and thus the optical centre C is very close to either of them. We therefore neglect the thickness of the lens and consider the emergent and incident rays as being in one straight line.

The optical centre of a thin lens is a point on the principal axis such that any ray which passes through it undergoes no deviation.

The optical centre varies in position with the different forms of lens.

Double convex lens . .	Inside.
Double concave lens . .	Inside.
Plano convex lens . . .	On convex side.
Plano concave lens . . .	On concave side.
Convex meniscus . . .	Outside.
Concave meniscus . . .	Outside.

To find the image of a point formed by direct refraction through a thin concave lens.

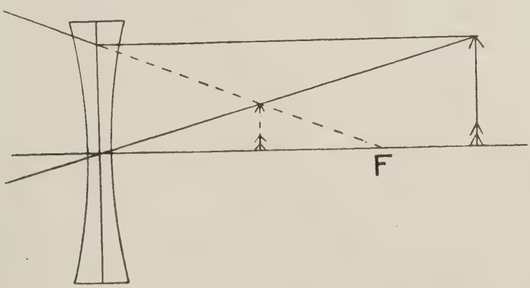


Fig. 33.

We need only trace the path of two rays.

1. A ray parallel to the principal axis which, after refraction, appears to pass through the principal focus.

2. A ray passing through the optical centre, which has its direction unchanged.

The object may be between the lens and the principal focus F, when the image will be virtual, erect, diminished in size, and between the lens and F, or outside F, when the image is virtual, erect, diminished, and between the lens and F.

To find the image of a point formed by direct refraction through a thin convex lens.

If the point is :

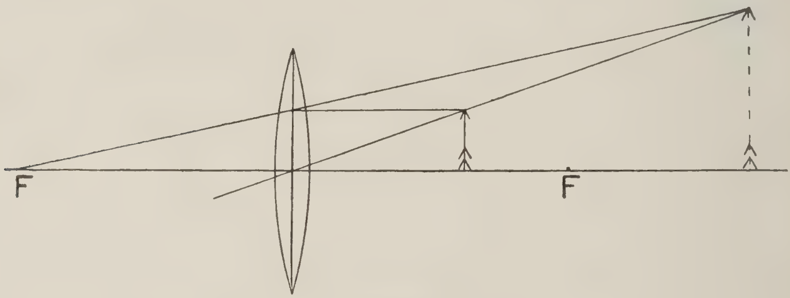


Fig. 34.

(*a*) At a distance less than *f*, the focal length.

The image is virtual, erect, magnified, and on the same side of the lens as the object.

(*b*) At the principal focus.

The image is at infinity.

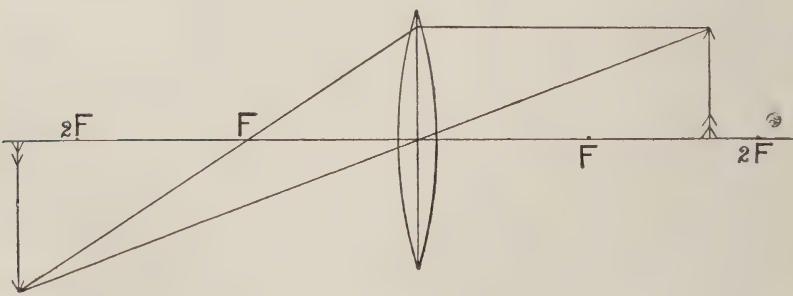


Fig. 35.

(*c*) At a distance greater than f, but less than $2f$.

The image is real, inverted, magnified, on the other side of the lens to the object, and outside 2F.

(*d*) At 2F.

The image is real, inverted, of the same size, on the other side of the lens to the object, and at 2F.

(*e*) Outside 2F, but at a distance less than infinity.

The image is real, inverted, diminished, on the other side of the lens, and between F and 2F (cf. (*c*)).

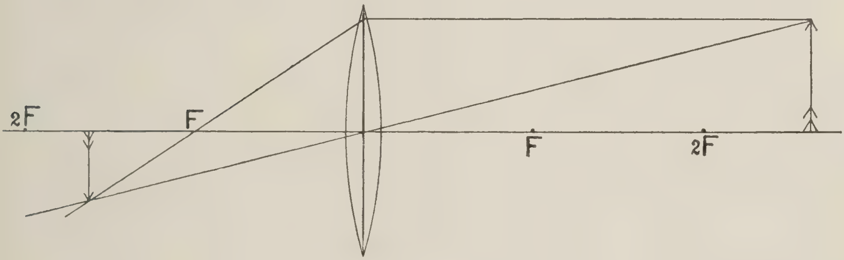


FIG. 36.

Conjugate Foci.—An object in the medium on the right of the lens is brought to a focus at a point in the medium on the left of the lens, and since the path of the rays may be reversed, a point in the situation of the image on the left of the lens will form an image in the position of the object on the right of the lens.

These two points are called *conjugate foci*, and in the case of all reflecting and refracting surfaces an object and its geometrical image form conjugate foci.

To obtain a formula connecting the positions of an object and its image formed by direct refraction through a thin lens.

In the similar triangles PNQ, RNS (Fig. 37).

$$\frac{PQ}{RS} = \frac{NQ}{NS} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

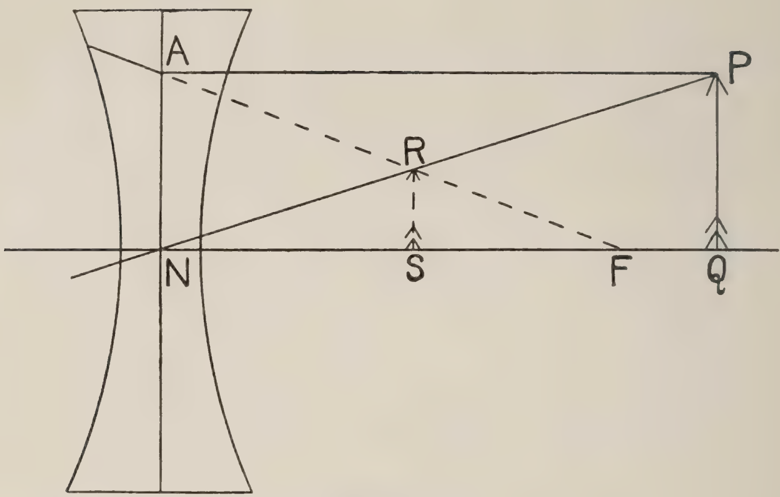


FIG. 37.

In the similar triangles AFN, RFS

$$\frac{\mathrm{AN}}{\mathrm{RS}} = \frac{\mathrm{FN}}{\mathrm{FS}}.$$

Since $$\mathrm{AN} = \mathrm{PQ},$$

$$\therefore \quad \frac{\mathrm{PQ}}{\mathrm{RS}} = \frac{\mathrm{FN}}{\mathrm{FS}} \quad \ldots \ldots \quad (2)$$

Then from (1) and (2)

$$\frac{\mathrm{NQ}}{\mathrm{NS}} = \frac{\mathrm{FN}}{\mathrm{FS}}.$$

$$\frac{u}{v} = \frac{f}{f - v}.$$

$$uf - uv = fv.$$

Dividing by ufv

$$\frac{1}{v} - \frac{1}{f} = \frac{1}{u},$$

or $$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}.$$

If it be remembered that the focal length is negative, and that all distances measured behind the lens are given a negative sign, this formula can be applied to convex lenses whatever be the position of the object.

Cylindrical Lenses.—Besides the spherical lenses described above, there are used, in ophthalmology, cylindrical lenses, so called because they are the segments of a cylinder of glass cut parallel to its axis. Such a segment forms a *convex* cylindrical lens, whereas a similar segment from the mould in which the cylinder was cast will form a *concave* cylindrical lens.

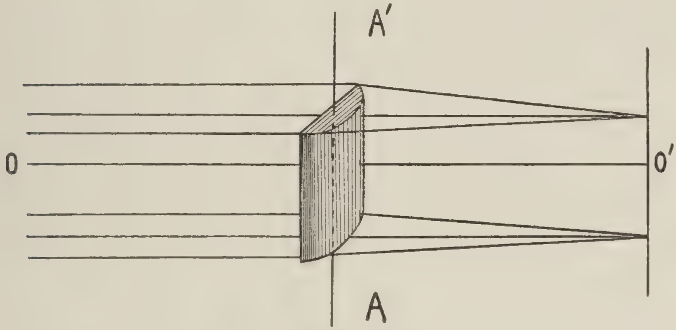


Fig. 38.

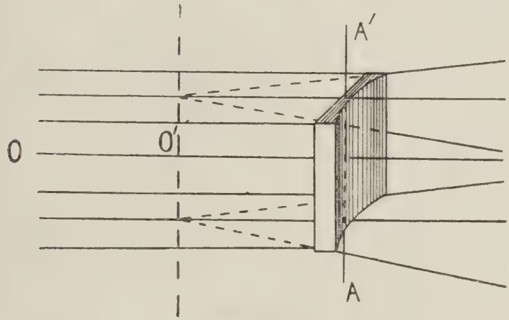


Fig. 39.

The axis of a cylindrical lens is parallel to that of the cylinder of which it is a segment, and must not be confused with the optic axis of a spherical lens, which is the line joining the centres of curvature of its two surfaces. In the direction of its axis the cylindrical lens acts as a plane lamina with parallel sides which we have seen has no effect upon rays of light that strike it normally. In the direction at right angles to its axis

the cylindrical lens is spherical, either convex or concave, as the case may be, and in this direction a cylindrical lens acts as a plano convex or plano concave lens causing rays to converge to or diverge from a point.

The image of a point formed by a cylindrical lens is not a point but a line, the *focal line* of the lens, which is parallel to its axis, and as a result no distinct image is formed.

Combination of Two Lenses.—Suppose we have two thin convex lenses, A and B, of focal lengths f_1 and f_2.

Consider the first lens, A :

$$\frac{1}{v_1} - \frac{1}{u} = \frac{1}{f_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Consider the second lens, B :

$$\frac{1}{v} - \frac{1}{u_2} = \frac{1}{f_2}.$$

Let the image formed by A act as the object of B.

Suppose the lenses to be in contact, and, being thin, neglect their thickness.

Then $$u_2 = v_1.$$

$$\therefore \quad \frac{1}{v} - \frac{1}{v_1} = \frac{1}{f_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Let the object be at infinity :

$$u = \text{infinity}.$$

Then $$\frac{1}{u} = 0 \text{ and } v_1 = f_1.$$

$$\therefore \quad \frac{1}{v} = \frac{1}{f_1} + \frac{1}{f_2}.$$

Let F = focal length of the combined lenses A and B.

Then $$v = \mathrm{F}.$$

$$\therefore \quad \frac{1}{\mathrm{F}} = \frac{1}{f_1} + \frac{1}{f_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Therefore the power of a combination of lenses in contact is the algebraical sum of the power of the lenses.

Suppose the lenses are not in contact, but separated by a distance C, then, with the object at infinity,

$$u_2 = f_1 - \mathrm{C}.$$

$$\therefore \qquad \frac{1}{v} - \frac{1}{f_1 - \mathrm{C}} = \frac{1}{f_2},$$

that is,

$$\frac{1}{v} = \frac{1}{f_2} + \frac{1}{f_1 - \mathrm{C}},$$

$$\frac{1}{\mathrm{F}} = \frac{1}{f_2} + \frac{1}{f_1 - \mathrm{C}}.$$

Combination of Cylindrical Lenses.—From the above consideration of spherical lenses in contact, it will be apparent that if two cylindrical lenses are held in contact with their axes parallel, their combined power will be the sum of the power of each lens.

If now the lenses be held with their axes at right angles to one another, there will be two focal lines perpendicular to one another through which all the rays must pass. When the two lenses are of the same power and sign these two lines will intersect, and it will be found that the combined action is that of a spherical lens of the same sign and power as either of the cylindrical lenses. For example: a + 2 D cyl. ax. 90 combined with a + 2 D cyl. ax. 180 will be equal to a + 2 D sph.

A combination of two cylindrical lenses of the same sign and different power with their axes at right angles will be equal to a spherical lens and a cylindrical lens of the same sign. For example: a combination of a + 4 D cyl. ax. 90 with a + 2 D cyl. ax. 180 will be equal to a + 2 D sph. with a + 2 D cyl. ax. 90, as will be seen from a consideration of a combination of two cylindrical lenses of the same sign and power at right angles to each other.

A combination of a spherical lens with a cylindrical lens of the same power but opposite sign, will be equal to a cylinder of the same power but *opposite* sign whose axis is at right angles to that of the given cylinder. For example, a + 3 D sph. combined with a – 3 D cyl. ax. 90 is equal to a + 3 D cyl. ax. 180.

A combination of a spherical lens with a cylindrical lens of opposite sign and *lower* power will be equal to a spherical lens of the same sign with a numerical value equal to that of the difference of the value of the spherical and cylindrical lenses combined with a cylindrical lens of the same value as the given cylindrical lens but of opposite sign with an axis at right angles to that of the given cylindrical lens. For example, a + 3 D sph. combined with a — 2 D cyl. 180 is equal to a + 1 D sph. combined with a + 2 D cyl. ax. 90.

CHAPTER II

THE OPTICAL CONSTANTS OF THE EYE

The refracting apparatus of the eye consists of several structures which, when combined in action, form a very strong refracting system of short focal length, so that the eye may be as compact as possible. These structures are the cornea, aqueous humour, crystalline lens and vitreous humour, and thus rays of light entering the eye are refracted in this order, by the anterior surface of the cornea, the posterior surface of the cornea, the aqueous humour, the anterior surface of the lens, the substance of the lens, the posterior surface of the lens, and last, by the vitreous humour.

The study, therefore, of the dioptric mechanism of the eye presents many problems before accurate knowledge of the behaviour of rays on their way to the retina can be obtained. It will be necessary to know the radii of curvature of the various surfaces, their relative position one to the other, and the indices of refraction of the media. The usual methods of the laboratory do not apply in many instances, as direct measurements with instruments cannot be applied to the living eye, and after death such profound changes take place in these delicate structures, as well as in the curvature of the surfaces that observations in such circumstances are of small value.

The indices of refraction of the media were the more easily investigated, as material could be procured very soon after death and examined with the various forms of refractometer.

For the measurement of the radii of curvature of the surfaces special methods had to be devised, as well as for the relations of the surfaces one to the other.

The indices of refraction of the various transparent media of the eye have been measured many times: these figures vary only a little, and the following are the most recent results:—

Refracting Medium.	Index of Refraction.
Cornea	1·3771
Aqueous humour . .	1·3374
Capsule of lens . . .	1·3599
Outer layers of lens . .	1·3880
Middle layers of lens . .	1·4060
Nucleus of lens . .	1·4107
Vitreous humour . .	1·3360

There are several features in these figures that call for comment: first, the indices of refraction of the aqueous and vitreous are approximately the same, and equal to that of water. The lens is not homogeneous, but is formed of a series of concentric layers of medium of different consistency, so that the index increases layer by layer towards the nucleus where the index is highest. Not only so, but the curvature of these superimposed layers also increases in the same direction, *i.e.*, towards the nucleus, which is, compared with the general outline of the lens, approximately globular.

After death there is frequently produced an artificial separation between the cortical layers and the nucleus itself. Tscherning has shown in the ox, that instead of there being three images of Purkinjé, one from the cornea, and the others from the anterior and posterior surfaces of the lens respectively, there appear two others, one from the convex anterior surface of the nucleus, and a smaller one from the concave posterior surface of the nucleus. These images are much smaller than the images formed on the anterior and posterior surfaces of the lens itself, and so prove that the curvature of the nucleus is greater than that of the surfaces of the cortex. The following diagram is copied from Tscherning:—

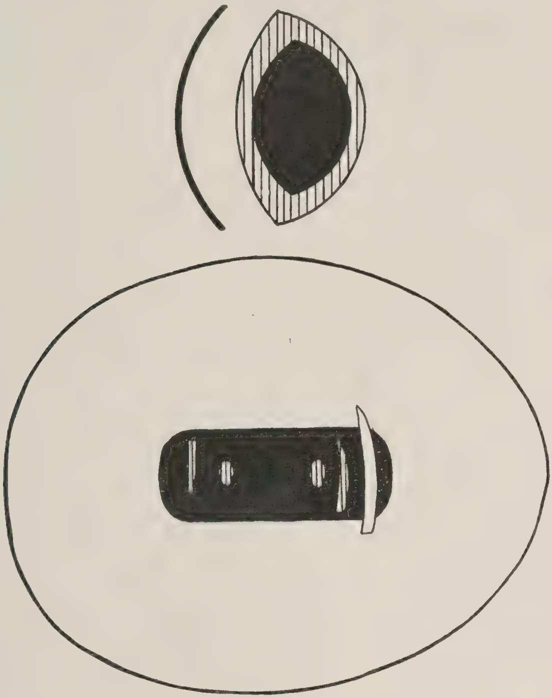


FIG. 40.

We may thus consider the lens as composed of many layers of divergent menisci, increasing in power and refractive index until the nucleus itself is reached, which in its turn may be considered as a very highly convex lens, with a still higher index of refraction.

Thus, as Hermann says: "The concavo-convex menisci neutralise part of the effect of A, and the less so in proportion as their refractive index is lower. Since B, C, have a lower refractive index than A, the total action of the lens is greater than if it had the same index as A, *i.e.*, if the lens were homogeneous and had the high refractive power of the nucleus throughout" (Fig. 41).

The index of refraction of the cornea is slightly higher than that of the aqueous and vitreous humours, and also of the tears that bathe it; however, as the anterior and posterior surfaces

of the cornea are approximately parallel, rays passing through it will be refracted as by a plate, and will continue their path parallel to the previous direction and only displaced to one side. We may, therefore, consider the eye as though it consisted of three media only, the aqueous, lens and vitreous, separated by surfaces that are approximately centred.

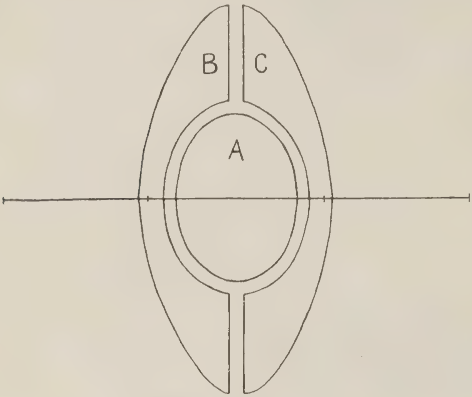


Fig. 41. (Luciani.)

The Curvature of the Surfaces.—As was stated above, direct measurements cannot be applied to the living eye in estimating the curvature of the cornea and lens, and after death so much shrivelling takes place in these delicate structures that these usual means have failed.

The cornea, and the anterior and posterior surfaces of the lens each behave as mirrors, the cornea and anterior surface of the lens as convex mirrors, the posterior surface of the lens as a concave mirror.

Fig. 42.

To observe the Images of Purkinjé.—If a candle be placed in front of and on the same level as an observed eye so that the line which unites the flame with the eye and its optic axis makes an angle of 35°, then if the observer place himself at his own least distance of near vision on the opposite side, making an equal angle with the optic axis of the observed eye, three (and if care be taken, four) images of the candle flame appear.

A bright, erect image of the candle of medium size will be formed on the anterior surface of the cornea: it is most easily recognised, and corresponds to the bright spot of light seen in the cornea of any one facing a light.

Just to one side of this is seen a smaller and less distinct erect image of the candle flame (not shown in the diagram) formed on the posterior surface of the cornea.

Outside this image, and nearer the middle of the pupillary area, is seen a larger, less bright, and more diffuse erect image of the candle flame, reflected by the convex anterior surface of the lens. It is larger than the first corneal image, because the anterior surface of the lens is less curved, less bright because the difference between the refractive indices of the aqueous and lens respectively is slight, and, consequently, less rays are reflected. It will be found that this image appears to move in the same direction as the head of the observer, showing that the image is formed behind the plane of the pupil.

The remaining image is much smaller, inverted, and, therefore, a real image, and is formed by the posterior concave surface of the lens. It is less bright than the first corneal image for a similar reason as in the case of the image from the anterior surface of the lens, and smaller because reflected by a surface of less radius of curvature than that of the cornea. With a movement of the observer's head, very little movement appears in the image, which is, therefore, formed approximately in the plane of the pupil. Advantage is taken of these images to measure the radii of curvature of the refracting media of the eye.

The Formation of Images in Convex Mirrors.—The image produced by a convex mirror is an erect image, diminished in size and placed apparently behind the mirror. Since the greater the curvature of the mirror the smaller the image, it is possible, by measuring the size of the image of a given object formed in the mirror, to deduct the radius of curvature of the mirror.

Let AB be a convex mirror, C its centre of form, OC its radius of curvature, and F its principal focus.

Let PQ be an object.

Trace two rays.

(1) PO passing through the centre of curvature.

(2) A parallel ray which, after reflection, will pass through the principal focus.

We find that the image is :

Virtual.

Erect.

Behind the mirror, and since it must always be confined between the converging lines PO, QO, it must be diminished in size.

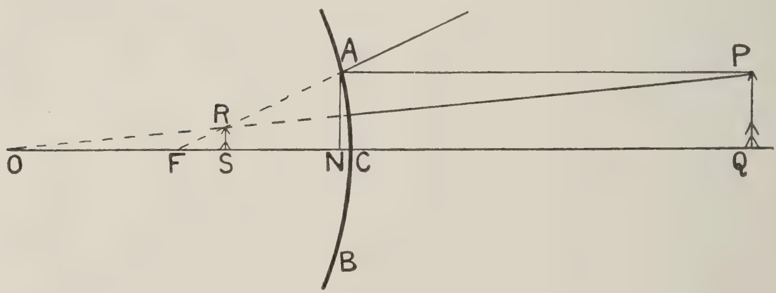


FIG. 43.

Now PQ : RS : : QC : CS.

Therefore $\quad CS = \dfrac{QC \times RS}{PQ}$.

If PQ be at infinity, then RS must be very small and very near F, *i.e.*, CS is nearly equal to CF.

CF is equal to $\frac{1}{2}$OC.

Let
$$PQ = o$$
$$RS = i$$
$$QC = u$$
$$OC = R.$$

Then
$$R = \frac{2ui}{o}.$$

For example, in determining the radius of curvature of the cornea, the object used was 1 metre in length at a distance of 3·8 metres. The size of the reflected image was 1 mm.

Therefore $$R = \frac{2 \times 3{,}800 \times 1}{1{,}000} = 7{\cdot}6 \text{ mm.}$$

In the case of an ordinary convex mirror in which we wish to find the size of the reflected image, this may easily be done by direct measurement with a microscope in which a millimetre scale is fixed at the principal focus of the objective. In the case of the eye this is not possible, owing to the difficulty presented by slight movements of the eye which would make the measurement, of such very small images, inaccurate.

An instrument, the ophthalmometer, was designed by Helmholtz to measure *indirectly* the size of reflected images on the cornea and lens, but before we can understand its practical application it is necessary to examine its optical principles.

The Principle of the Helmholtz Ophthalmometer.—When a ray of light falls normally on a glass plate it passes through without refraction. If, however, it strikes the plate obliquely, then the ray is deviated from its course, but after again reaching the original medium in which it was travelling, it is again refracted so as to be parallel to its original direction, although laterally displaced, the displacement depending upon the angle of incidence of the ray.

Let ABCD (Fig. 44) be a plate of flint glass, and *ac* a ray impinging obliquely upon its surface.

It is refracted in the direction *ci*, and on passing again into the air it is a second time refracted in the direction *il*, and it is parallel to *ac*.

Draw *nc* perpendicular to AB and continue it to *k*.

Draw *mi* perpendicular to DC and continue it to *o*.

The angle *acn* is equal to the angle *mil*, being formed by parallel lines falling upon parallel surfaces.

The angle *acn* is the angle of incidence, *i.e.*, α.

The angle *kci* is the angle of refraction, *i.e.*, β.

Now the sine of the angle of *incidence* bears to the sine of the angle of *refraction* a constant ratio which depends only on the two media and on the nature of the light.

I.e., $\frac{\sin \alpha}{\sin \beta} = \mu$, *i.e.*, the index of refraction between the two media.

The eye at l will see the point a as if it were at b, that is, the

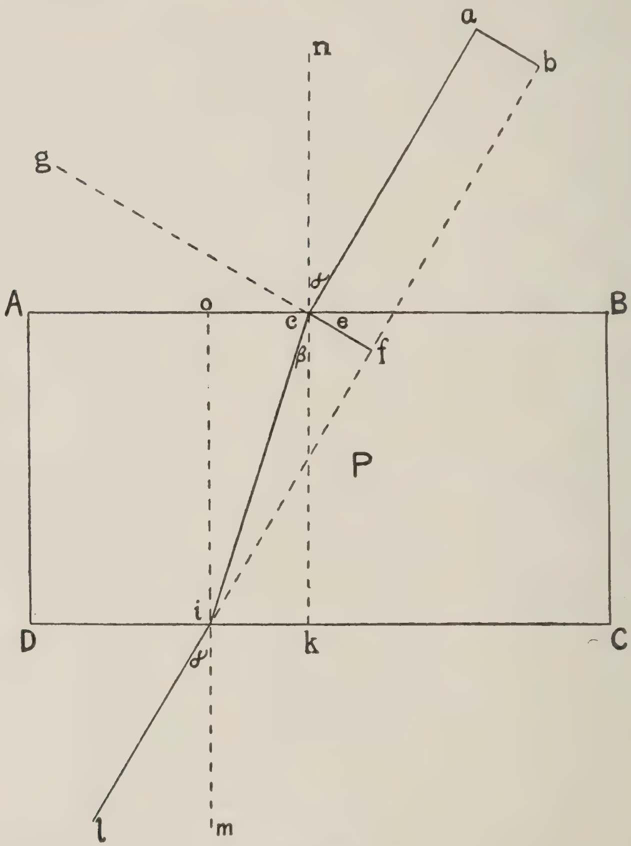


Fig. 44.

point a has been displaced by the glass plate the length of the line ab.

It is required to find the amount of this displacement.

Draw cf parallel to ab, and therefore equal to ab, and let cf be e. Then e represents the displacement.

Let P be the thickness of the plate.

In the triangle *cif*

$$\frac{e}{ci} = \sin cif$$
$$= \sin (oif - oic)$$
$$= \sin (\alpha - \beta)$$
$$\therefore \quad e = ci \sin (\alpha - \beta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In the triangle *oic*

$$\frac{oi}{ci} = \cos oic$$
$$= \cos \beta.$$
$$\therefore \quad ci = \frac{oi}{\cos \beta} = \frac{P}{\cos \beta}.$$

Substituting this value for *ci* in equation (1)

$$e = \frac{P \sin (\alpha - \beta)}{\cos \beta}.$$

If we have to deal with two plates displacing the image equally in opposite directions the displacement will be double.

Then if E be the total displacement by the two plates

$$E = 2P \frac{\sin (\alpha - \beta)}{\cos \beta}.$$

The Helmholtz ophthalmometer consists of two plates of glass of known thickness and index of refraction, placed side by side, so that each covers half of the objective of a short distance

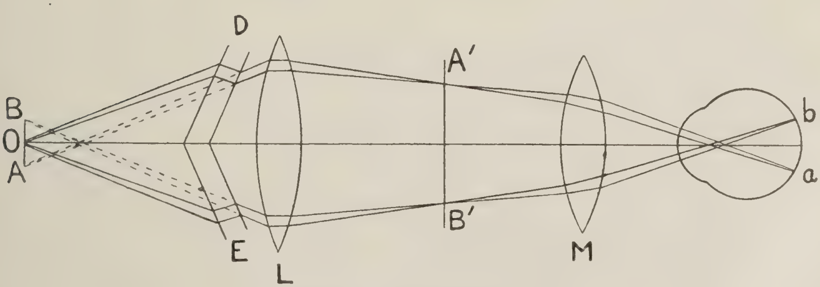


FIG. 45. (After Suter.)

telescope; the axis of the telescope coincides with the plane of separation of the glass plates. These plates can be inclined

one to the other at known angles, and so the angle of incidence of light falling on them from a point in front can be varied and measured.

A pencil of light from O meets the plate D and is refracted as in the figure; the rays on emergence are parallel to their direction before entering the plate, but have undergone lateral displacement owing to the thickness of the plate, so that they appear to come from A.

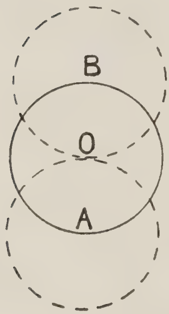


Fig. 46.

Likewise, that part of the pencil that passes through E appears to come from B, and so, if O represents a small object, there will appear, after refraction through the plates, two similar objects at A and B.

L is the objective of the telescope and by it two real images of A and B will be formed at A′ and B′ respectively. The eye-piece of the telescope M is so arranged that its principal focus coincides with the images A′ and B′, hence the eye receives parallel rays which, without accommodation, come to a focus upon its retina at a and b.

If a circle, whose centre is O, be viewed through two inclined plates, and if the double images are separated to such an extent that the two circles A and B appear to touch at O, then each plate has displaced the corresponding image through half the diameter of the circle, and the total displacement AB gives the diameter of the circle.

The angle of incidence being measurable and the index of refraction and thickness of the plates being known, this displacement can be calculated from the formula

$$E = \frac{2\,P \sin(\alpha - \beta)}{\cos \beta}.$$

If O be the image formed at the surface of the cornea or lens of an object of known size placed at a known distance, then all the necessary data are available for the calculation of the radius of curvature of the surface from the formula

$$R = \frac{2ui}{o}.$$

The radii of curvature of the dioptric surfaces of the eye thus determined are :

Anterior surface of the cornea .	7·98	mm.
Posterior surface of the cornea .	6·22	,,
Anterior surface of the lens . .	10·20	,,
Posterior surface of the lens . .	6·17	,,

Respective Distances of the Dioptric Surfaces.—Besides determining the curvature of the refracting surfaces of the eye, it is also necessary to know their respective distances one from the other along the optic axis.

These have been determined, and are as follows :

From the anterior surface of the cornea to that of the lens = 3·6 mm.

From one surface of the lens to the other = 4·0 mm.

Let S_1 and S_2 be two surfaces, say, of the cornea and lens having their centres of curvature at C_1 and C_2 respectively, and let d be the distance between their poles measured along the optic axis. S_1C_1 represents the radius of curvature of the cornea R, already determined.

In the ophthalmophakometer used by Tscherning for the determination of these distances in the eye, $S_1S_2C_1$ is the visual line of the eye which fixes a point M on a graduated arc. Two sources of light A and B and a telescope are also mounted on movable carriages on the arc.

A ray AS_2 is directed from A to the summit of the anterior surface of the lens and the telescope is moved along the arc until it receives the reflected ray from S_2. The angle AS_2L is measured on the arc, and as the incident and reflected rays form equal angles with the visual line MC_1, the angle β is equal to half the angle AS_2L.

With another source of light B, an image is formed at the anterior surface of the cornea, and the cursor is displaced until the image of this source is superimposed upon that of the source A reflected by the anterior surface of the lens at S_2. The angle γ is then determined from the angle BIL, which is measured on the graduated arc.

A formula can now be derived from which the distance S_1S_2 or d can be calculated.

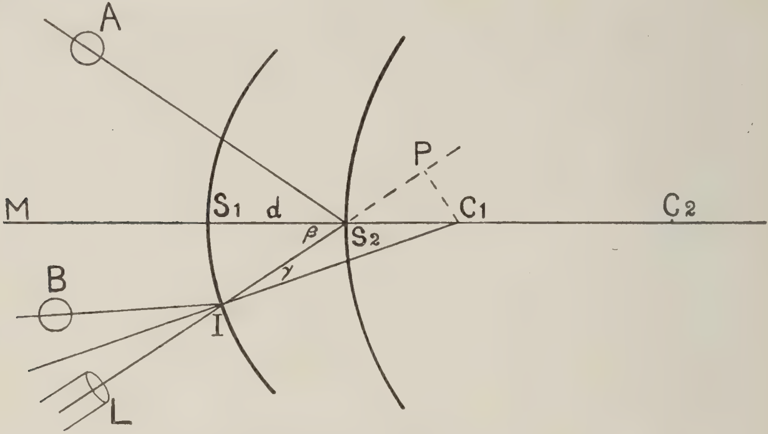


Fig. 47. (After Tscherning.)

In the figure, produce IS_2 and drop a perpendicular C_1P to it from C_1.

Then in the triangle C_1IP

$$\frac{C_1P}{C_1I} = \sin \gamma,$$

i.e., $$C_1P = R \sin \gamma.$$

In the triangle C_1S_2P

$$\frac{C_1P}{C_1S_2} = \sin \beta,$$

i.e., $$C_1P = C_1S_2 \sin \beta$$
$$= (R - d) \sin \beta$$

Equating these two values for C_1P

$$R \sin \gamma = (R - d) \sin \beta$$
$$d \sin \beta = R (\sin \beta - \sin \gamma).$$
$$\therefore \quad d = \frac{R (\sin \beta - \sin \gamma}{\sin \beta}.$$

Certain corrections have to be made, knowing that the optic and visual axes do not coincide, and also owing to the refractive power of the cornea and aqueous, the value of S_1S_2 is only apparent.

Indices of Refraction of the Media.—The index of refraction

of a liquid or a solid can be determined by finding its *critical angle.* This is the principle of the Abbé refractometer, and, by its help, very accurate determinations have been made of the various media of the eye.

The Optical Constants of the Eye.

	mm.
Position of the anterior surface of the cornea . .	0·00
Position of the posterior surface of the cornea . .	1·15
Position of the anterior surface of the lens . . .	3·54
Position of the posterior surface of the lens . .	7·60
Radius of curvature of the anterior surface of the cornea	7·98
Radius of curvature of the posterior surface of the cornea	6·22
Radius of curvature of the anterior surface of the lens .	10·20
Radius of curvature of the posterior surface of the lens	6·17
Index of refraction of the air	1·00
Index of refraction of the cornea	1·37
Index of refraction of the aqueous humour . . .	1·33
Index of refraction of the lens (total)	1·42
Index of refraction of the vitreous	1·33

We are now in a position to discuss the dioptric values of the var'ous refracting media of the eye, knowing their radii of curvature, indices of refraction and position on the optic axis.

The Cornea.—The cornea bounds the division between two media, the air in front, the aqueous behind. As the indices of refraction of these two media differ, so will the power that the cornea exerts upon rays differ, depending upon whether they pass from a medium of less density to one of greater density, or *vice versâ.* As the refractive power of a lens depends upon the relation between its index of refraction, and that of the surrounding medium, so we shall find that rays passing through the cornea to the air will be brought sooner to a focus than is the case with rays passing from the cornea into the aqueous. (*See* p. 25, p. 135.)

Thus we find that the anterior focal length of the cornea is 24 mm., whereas its posterior focal length is 32 mm.

The Lens.—In the case of the lens, the medium on either side of it has practically the same index of refraction, *i.e.*, 1·33

for both the aqueous humour and vitreous. The lens itself has a mean refractive index of 1·42.

We have to consider, however, the refractive power of the anterior and posterior surfaces of the lens respectively, and in each case the surface bounds two media of unequal index of refraction; moreover, each surface has its own radius of curvature. Thus, the anterior surface, with a radius of curvature of 10·20 mm., separates the aqueous with an index of 1·33 from the lens substance with an index of 1·42, whilst the posterior surface, with a radius of 6·17 mm., separates the vitreous humour with an index of 1·33 from the substance of the lens.

The anterior focal length of the anterior surface of the lens is 150·73 mm., and its posterior focal length 160·93 mm.

For the posterior surface of the lens the figures are :—

Anterior focal length . . .	97·35 mm.
Posterior focal length . . .	91·18 ,,

Taking now the lens as a whole, knowing its thickness to be 4 mm., we may consider it as a biconvex lens, so situated that the medium on either side of it has the same index of refraction, and so the anterior and posterior focal lengths will be the same, namely, 56·3 mm., giving a dioptric value of 17·8.

The Schematic Eye.—We have now all the data required for considering the eye as a whole as an optical apparatus. When rays of light, after traversing one medium meet another, and yet a third, each with a different radius of curvature and with different index of refraction, the problem of calculating the position and size of the resulting image becomes one of great difficulty and complexity. Taking the first surface, we might find the position and size of the image formed by it, and then, using this image as the object of the second surface, deal similarly with the image formed by it, and so on through all the various surfaces and media of the eye. This would always be necessary when dealing with systems of lenses in which their thickness could not be neglected, and not so near together that their distance one from the other could be ignored.

The investigations of Gauss, extended by Listing, have provided us with a much simpler method of dealing with thin

axial pencils of light, the following being an account of their conclusions.

For every dioptric system, formed of any number of media bounded by *centred* spherical surfaces, there exist three pairs of cardinal points, called principal foci, principal points and nodal points, these last being added by Listing. They are all situated upon the principal axis of the system.

The first principal focus (ϕ') is the point on the principal axis at which parallel rays emerging from the system intersect.

The second principal focus (ϕ'') is the point on the principal axis at which parallel rays entering the system intersect.

The principal points ($h'h''$) are such that an incident ray passing through the first principal point passes after refraction through the second principal point, but the incident and emergent rays are not necessarily parallel in direction. The second principal point is the image of the first principal point.

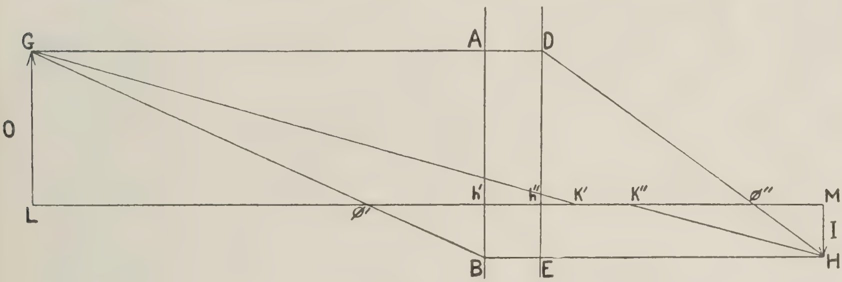


FIG. 48.

The nodal points ($k'k''$) are such that every ray which before refraction is directed towards the first nodal point, after refraction appears to come from the second nodal point, and takes a direction parallel to the direction of the incident ray.

These two lines are the lines of direction of the system, and are comparable to the line drawn through the optic centre of a surface bounding a single refracting medium in a simple system.

The nodal points are the image one of the other.

Two planes drawn through ϕ' and ϕ'' at right angles to the principal axis in the case of axial pencils are called the first and second focal planes respectively, and similarly two planes

drawn through h' and h'' are known as the first and second principal planes.

Rays that originate from a point on the first focal plane are, after refraction, parallel to each other and to the lines of direction.

Incident rays parallel to each other, after refraction, intersect in some point on the second focal plane, and at a point where the corresponding line of direction cuts the second focal plane.

The principal planes are such that an incident ray and its corresponding emergent ray cut the two principal planes in two points, situated on the same side of and at the same distance from the principal axis ; thus the second principal plane is the image of the first principal plane.

The first principal focal distance, F′, is the interval $\phi' h'$ which separates the first principal focus and the first principal point.

The second principal focal distance, F″, is the interval $\phi'' h''$, which separates the second principal focus and the second principal point.

The first focal distance, $\phi' h'$, is equal to the distance between the second principal focus and second nodal point, $\phi'' k''$.

The second focal distance, $\phi'' h''$, is equal to the distance between the first principal focus and first nodal point, $\phi' k'$.

Thus the distance between the first principal point and first nodal point is equal to the distance between the second principal point and second nodal point.

To Construct an Image formed by a System of Cardinal Points.—The intersection of two rays only is required, as we have seen in the consideration of thin lenses when we wish to find the image of the point G.

1. The ray GA, parallel to the axis, will cut the second principal plane in D, so that Dh'' is equal to Ah', and must pass through ϕ'' in the direction DH.

2. The ray GB passing through ϕ' is, after refraction, parallel to the axis, and passes in the direction EH.

3. The ray Gk', meeting the first nodal point k', will pass through k'', in the direction k''H, parallel to its first direction.

Conjugate Distances, and the Magnification in Conjugate Planes, referred to Focal Points.—In the figure (48)—

The triangles $GL\phi'$, $Bh'\phi'$ are similar.

Putting $GL = y$, $Bh' = y'$ and $L\phi' = l'$, $\phi'h' = F'$,

we have
$$\frac{GL}{Bh'} = \frac{L\phi'}{\phi'h'},$$

that is
$$\frac{y}{y'} = \frac{l'}{F'}.$$

Similarly, from the similar triangles $D\phi''h''$, $HM\phi''$.

Putting
$$M\phi'' = l'',\ \phi''h'' = F''$$
$$Dh'' = Ah' = GL = y,$$
$$MH = Eh'' = Bh' = y',$$

we have
$$\frac{y}{y'} = \frac{F''}{l''} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The distances l' and l'' are the axial distances of conjugate points L and M measured from corresponding focal points.

The ratio $\frac{y'}{y}$ is the magnification (M) so that

$$M = \frac{F'}{l'} = \frac{l''}{F''} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

From which we obtain

$$l'l'' = F'F'' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

from which equation the distance l'' may be calculated from the object distance l' if F' and F'' be known.

Conjugate Distances referred to the Principal Points.—In figure 48—

put
$$Lh' = p'$$
$$Mh'' = p''.$$

Then
$$l' = p' - F'$$
$$l'' = p'' - F''$$

so that $l'l'' = F'F''$ becomes $(p' - F')(p'' - F'') = F'F''$

or
$$p'p'' - p'F'' - p''F' + F'F'' = F'F''$$

or
$$p'p'' = p'F'' + p''F'.$$

Dividing by $p'p''$

$$\frac{F'}{p'} + \frac{F''}{p''} = 1.$$

We have now the information wherewith to construct a simplified or schematic system having the same refraction as

the human eye, by adding together the corneal and lenticular systems, and so finding the six cardinal points, the two principal foci, two principal points and two nodal points of the schematic eye.

By applying the rules and calculations of Gauss to the optical constants already determined, Helmholtz arrived at

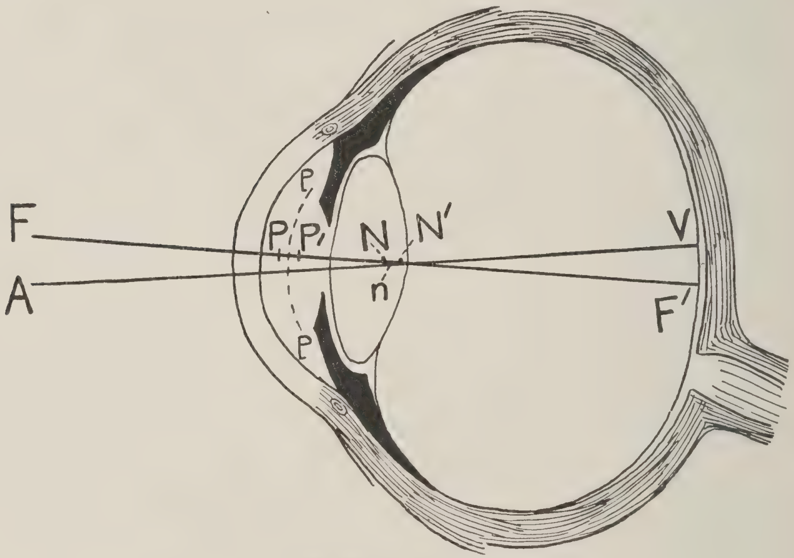


Fig. 49. (Helmholtz.)

the following table of measurements, in which the distances in millimetres are taken from the apex of the cornea.

First principal point, P . . .	1·75 mm.
Second principal point, P′ . .	2·10 ,,
First focal point, F . . .	13·75 ,,
Second focal point, F′ . . .	22·79 ,,
First nodal point, N . . .	6·96 ,,
Second nodal point, N′ . . .	7·32 ,,
Anterior focal distance, PF . .	15·50 ,,
Posterior focal distance, P′F′ . .	20·70 ,,

As the two principal points, and, therefore, the two nodal points, are so close together, there can be no great error in

taking an intermediate point as the one principal point, and dealing similarly with the nodal points.

In this way we arrive at the "reduced eye," in which the several surfaces and media of the actual eye are replaced by an ideal spherical surface, having one nodal point; the two media which the surface separates are supposed to be the air on one side and water on the other.

So as to deal in round numbers, a much simpler method for rough clinical work, Donders still further simplified the

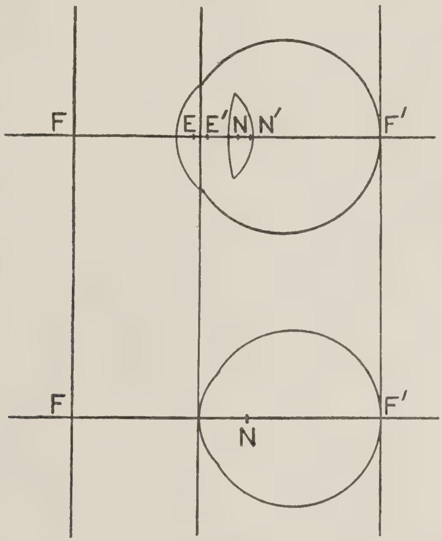


FIG. 50.

"reduced eye" so that we have now the following measurements :

Distance of the theoretical surface from the anterior surface of the cornea . .	2 mm.
Radius of curvature of the theoretical surface	5 ,,
Relative index of refraction . .	$= \frac{4}{3} = 1{\cdot}33$
Anterior focal distance	15 mm.
Posterior focal distance	20 ,,

The Size of the Retinal Image.—With the reduced eye of Donders it is not difficult to calculate the size of retinal images, and the matter is of interest in measuring the size of the diseased area of the retina that corresponds to a scotoma in the field of vision.

We require to know the size of the object (the scotoma) and its distance from the eye.

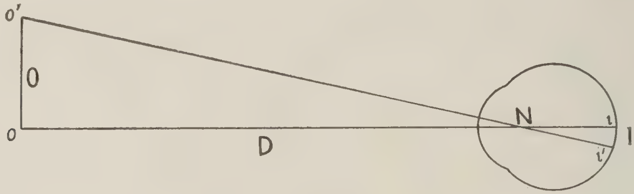


Fig. 51.

Let oo' be the object and from the extremities draw rays of direction through the nodal point N so as to cut the retina in ii'.

The triangles $oo'N'$, $ii'N$ are similar so that

$$ii' : oo' = iN : oN.$$

$$ii' = \frac{oo' \times iN}{oN}.$$

Let O be the size of the object oo', I the size of the image ii', and D the distance, oN.

Then $$I = \frac{O \times 15 \text{ mm.}}{D}.$$

For example, let the length of O be 1,500 mm., and D be 20,000 mm.

Then $$I = \frac{1{,}500 \text{ mm.} \times 15 \text{ mm.}}{20{,}000 \text{ mm.}} = 1{\cdot}13 \text{ mm.}$$

The Real and Apparent Position of the Pupil.—The colour and form of the iris can be seen in life, owing to the transparency of the cornea and aqueous humour. The varying diameter of the pupil can be observed and measured, but owing to the difference between the indices of refraction of the air and the media of the eye through which it is seen, the pupil is not seen in its real position, nor with the real diameter of its opening. We are observing the iris as we observe a stick partially immersed in

water, in which the part immersed appears bent towards the surface of the water, and in the same way, the iris appears displaced forwards, and the pupil appears of large size.

The iris is in relation to the cornea as an object placed behind a lens between its principal plane and its principal focus, thereby turning the lens into a simple magnifying glass, pro-

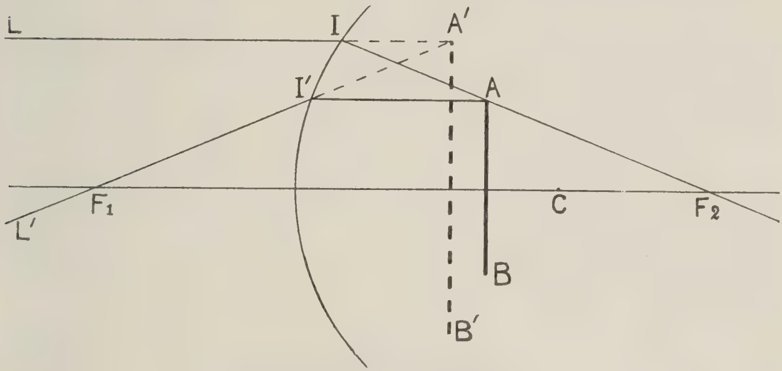


FIG. 52. (Morat and Doyon.)

ducing a virtual erect image of the pupil, magnified, and placed between the principal focus and the surface of the cornea.

Let A be the upper border of the pupil. Taking an incident ray AI′ parallel to the axis, which after refraction passes through the principal focus F_1, and another F_2AI, which after refraction takes a course IL parallel to the axis, the image of A will be found at A′. By a similar construction the image of B will be found at B′.

We know that the real position of the iris is upon the anterior surface of the lens, which is 3·5 mm. behind the anterior surface of the cornea.

By the general formula :

$$\frac{F'}{p'} + \frac{F''}{p''} = 1,$$

where F' is the anterior principal focus, F'' the posterior principal focus, p'' the distance of the object from the surface, and p' the distance of the image from the surface. (*See* p. 53.)

$$\frac{32 \cdot 47}{3 \cdot 54} + \frac{24 \cdot 53}{p'} = 1$$

$$p' = -3 \text{ mm.}$$

Hence the apparent position of the pupil is approximately half a millimetre nearer the cornea than the real position.

The magnification may be found by the formula :

$$\frac{I}{O} = \frac{F''}{l''}$$

in which l'' is the distance of the object from the posterior principal focus, that is, 32·47 mm. – 3·54 mm. = 28·93 mm., and it will be found that for a real diameter of 4 mm. the apparent diameter is 4·5 mm., that is, an increase in size of half a millimetre.

Visual Acuity: Visual Angle.—Visual acuity is the power we possess of distinguishing objects one from the other, and the details of visible objects.

Visual sensations are of three kinds, whereby we recognise the form, colour and brightness of an object, and the powers we possess of distinguishing these characters of an object are called the form sense, colour sense and light sense.

Comparing vision with touch, the degree of light sensibility corresponds with the degree of sensibility to pressure, while visual acuity corresponds with the power to distinguish two neighbouring tactile impressions, which, brought nearer together, are fused into one.

Now tactile acuity is measured with a Weber's compass ;

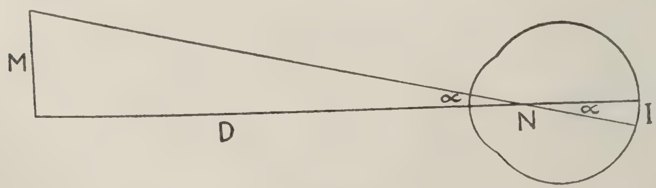


FIG. 53.

and its value is inversely proportional to the angular deviation of the arms of the compass.

Visual acuity is also measured by an angle

Let there be two luminous points, say two stars, which are just sufficiently separated to be distinguished : draw from each of these points a line that passes through the nodal point of the eye, and continue it to the retina. We have now two equal angles, contained by the intersecting lines, and the angle facing the retina may be compared to the angle of the compass, and is inversely proportional to the visual acuity (Fig. 53).

In the majority of individuals, visual acuity, measured by the above method, gives a minimum visual angle of one minute. This is merely an average, and is the standard adopted, although there are individuals whose minimum angle of visual acuity is half a minute, whilst, on the other hand, others have a minimum visual angle of three or four minutes.

To measure the visual acuity of a particular individual it is necessary to find the minimum angle under which two points are seen distinct, and we may take as its measure the separation of the two points, and this may be called the size of the object.

There are two means whereby we may vary the visual angle ; one consists in separating or approximating the two points, that is, diminishing or increasing the size of the object, and the other consists in keeping the relative position of the two points fixed, and then varying the distance between it and the eye under examination.

In the first instance, the visual angle varies directly with the size of the object, and in the second it varies inversely as the distance of the object.

Let the visual angle be α, M the size of the object, and D its distance. α varies as $\frac{M}{D}$, and since the visual acuity is inversely proportional to the visual angle, then V varies as $\frac{D}{M}$.

Thus we see that the visual acuity varies directly as the distance, inversely as the size of the object.

The Minimum Visual Angle compared with the Diameter of the Cones.—In order that two luminous points should be distinguished simultaneously, it is necessary that two cones should be

stimulated with an intermediate cone unstimulated. Histological research has shown that the diameter of a cone is ·004 mm., which is, therefore, the measure of the distance between two cones in these circumstances: this distance on the retina subtends at the nodal point of the eye an angle of one minute, which is the same as that subtended by two luminous points on the other side of the nodal point.

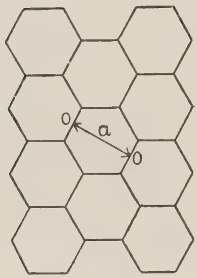


FIG. 54.

Variations of Visual Acuity with the Illumination.—Within certain limits visual acuity is increased by illumination. It has been found that visual acuity increases rapidly as the illumination is increased from zero up to 2-foot candles, but above this the increase is very slight. As a practical application of this, the illumination of test types used in clinical work should not fall below 3-foot candles.

Tests of Visual Acuity.—*Snellen's Test Type.*—In practice we make use of printed letters, either in the form of single letters or as sentences of printed matter. It was on the basis that the minimum visual angle was one minute (1′) that Snellen built up his charts.

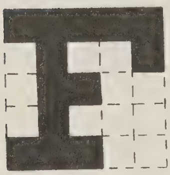


FIG. 55.

It was found that an object, such as a letter, to be seen by a normal person, required to subtend an angle five times greater than the lines or dots of which it was composed. The chart has printed in black, upon a white ground, letters of varying sizes, above which is indicated the distance at which they subtend an angle of five minutes.

When testing the visual acuity with Snellen's type we wish to know the distance at which the letters are read distinctly. Thus if D be the distance at which the letter should be read, which is indicated above the letters, and d the distance at which it actually can be read, and V is the visual acuity,

$$V = \frac{d}{D}.$$

If the line above which the 6 appears, is read at 6 metres distance, the visual acuity is equal to $\frac{6}{6}$ or 1 ; but if at 6 metres distance only the letter marked 60 is read, then it is equal to $\frac{6}{60}$ or $\frac{1}{10}$. In practice we do not reduce the fraction, but write it in full. It may happen that the line subtending five minutes at 5 metres distance is read at 6 metres, and so the visual acuity is $\frac{6}{5}$, that is, greater than normal.

If at 6 metres distance, which is the nearest point at which observations should be recorded, the largest letter cannot be distinguished, then the scale must be brought nearer to the eye, and the distance noted at which the largest letter is recognised, which will give a fraction, it may be, of 1/60. If at no distance can the largest letter be read, then, with the light behind the patient, the distance is recorded at which the fingers of the outstretched hand can be counted. If even this cannot be accomplished, the patient, with his back to the light, is asked if he can appreciate the light reflected by the outstretched hand moved in front of him, the record being made of the appreciation of hand movements, and, failing this, the patient faces the light whilst the hand is moved between the eyes and a light and, recorded as shadow perception. The last test is made by shining directly into the eye the light reflected by a mirror, when the record is made as to the perception or lack of perception of light.

Absolute and Relative Visual Acuity.—The *absolute* visual acuity can only be determined when an error of refraction in the eye under examination has been corrected, and the accommodation completely relaxed. The vision of an eye with an error of refraction uncorrected is the *relative* visual acuity. Consequently, when comparing the visual acuity of an eye during the progress of disease, it is necessary that the absolute visual acuity be recorded for these observations to be of value.

It is a matter of observation that the visual acuity obtained when both eyes are uncovered is greater than that obtained by each eye separately. This may sometimes be the case when the second eye uncovered is one with poor visual acuity.

Defects of the Eye as an Optical Instrument.—1. *Spherical Aberration.*—In the eye as in all optical systems homocentric rays, even when monochromatic, have a different focus, depending upon their being nearer to or farther from the optic axis. Those rays falling upon the central part of the lens are the least refracted; whereas those falling upon peripheral parts of the lens are more refracted in direct ratio to their distance from the optic axis. Rays therefore, converge, not to a point, but to a line.

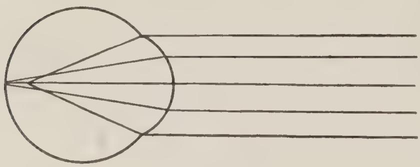


Fig. 56.

In ordinary lenses this phenomenon can be avoided by so grinding the lens that its curvature gradually decreases from centre to periphery.

Under normal conditions spherical aberration in the eye is reduced by the iris, the pupil of which acts as does the photographic camera "stop" in cutting off peripherally incident rays. The difference in curvature and refractive index of the nuclear and cortical portions of the lens also helps to reduce spherical aberration.

The difference in refraction of the rays entering the vertex of the cornea and at its margin is four dioptres.

Unless the pupil be artificially dilated, spherical aberration is of little importance, but when the pupil is dilated this aberration must be borne in mind when applying tests to the eye for measuring refraction, more especially retinoscopy.

The spherical aberration of the eye may be demonstrated by bringing a pin just within the near point of distinct vision, when it becomes blurred; if we now interpose between the object and the eye, a card perforated by a small hole, the object becomes distinct, owing to the reduction of diffusion circles, and also by the correction of spherical aberration.

Formerly it was thought that the spherical aberration of the eye was partly corrected by the fact that the cornea was most convex at its centre, and more flat at its periphery, but it has been shown that that portion of the cornea which is opposite a pupil of natural diameter is not less curved at its periphery than at its centre, and that it is only when the pupil is artificially dilated that the flattened peripheral part of the cornea comes into play in reducing aberration.

2. *Chromatic Aberration.*—As rays from the various parts of the spectrum do not travel at the same velocity through a lens, they are, therefore, unequally refracted, the short violet rays being focussed nearer to the lens than the long, red rays, and between these two extremes the other intermediate colours of the spectrum are focussed in the order of their wave length. The eye is hypermetropic 0·5 D for red rays, and myopic 1·5 D for blue rays.

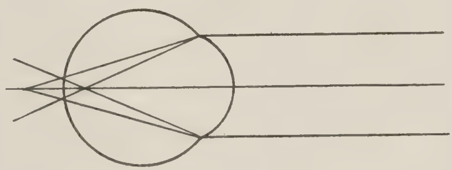


Fig. 57.

The defect in lenses is overcome by the use of a combination of lenses, convex and concave, made of substances of different refractive index. The eye has no such compensation, and remains myopic for violet rays and hypermetropic for red rays.

Cobalt blue glass mainly allows red and blue rays to pass : if a distant light, say a frosted electric bulb, be viewed through such a piece of glass, the red rays will be focussed upon the retina, and the blue rays in front, so that we shall see a red light surrounded by a blue circle. If, now, a source of light near at hand be viewed, the blue rays will be focussed upon the retina, and the red rays behind it, so that we shall see a blue light surrounded by a red circle.

This observation is the basis of a test for ametropia.

Angles α, γ, κ.—*The optic axis* is the line upon which the various refracting surfaces of the eye are centred, and, consequently, passes through the centre of the cornea and lens.

This line does not cut the fundus of the eye at the macula lutea, but somewhat to its inner side. Upon this line are found the *nodal point* of the eye, which is 7 mm. behind the vertex of the cornea, and the *principal point* of the eye, which lies upon an imaginary plane 2 mm. behind the apex of the cornea. There is also another point, the *centre of rotation* of the

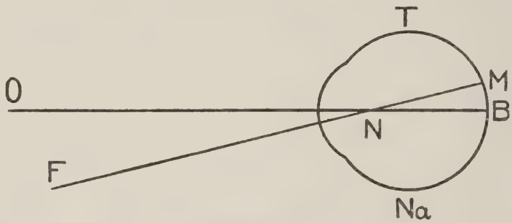


Fig. 58.

eye, upon the optic axis, which, in emmetropia, is 13·4 mm. behind the apex of the cornea. It is around this point that all movements of the eye take place.

The *visual axis* is a line drawn from the point of fixation through the nodal point, so as to cut the fundus in the macula lutea. If the optic axis cuts the fundus in the macula lutea,

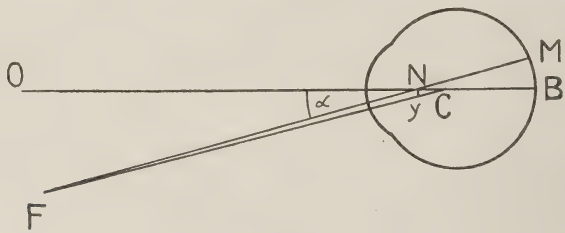


Fig. 59.

then the visual axis and optic axis coincide, but this is not usually the case.

The visual axis is a secondary axis which cuts the cornea on the nasal side of the optic axis, 4° up and 5° to the inner side, so that when the visual axis is directed straight forwards, the resultant deviation of the optic axis is 6° down and out.

The *fixation axis* is a line joining the point of fixation and the centre of rotation of the eye.

The angle α.—This is the angle formed at the nodal point, between the visual and optic axes.

That is, the angle ONF, in the diagram, in which ONB is the optic axis and FNM the visual axis, F being the point of fixation, and M the macula lutea.

The distance between the macula and the point where the optic axis cuts the retina is 1·25 mm., which is the distance MB. The line MN in Donders's reduced eye is 15 mm. The sine of the angle α is approximately $\frac{MB}{MN}$.

$$\therefore \qquad \sin \alpha = \frac{MB}{MN} = \frac{1{\cdot}25}{15{\cdot}00} = {\cdot}083.$$
$$= \sin 5^\circ.$$

The angle α therefore $= 5^\circ$.

If the distance MB be constant, it is seen that the size of the

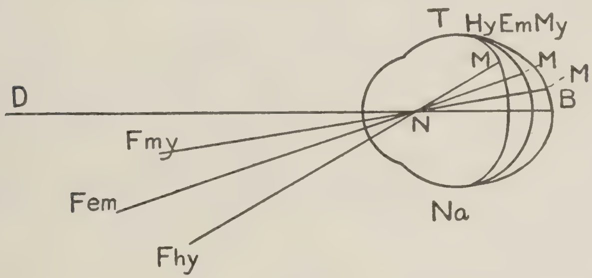


FIG. 60.

angle α must vary with the length of the line MN, and as this line varies in axial errors of refraction :

(*a*) In hypermetropia, in which the line MN is less than 15 mm., the angle α must be greater than 5°, and it is found in some cases to be as much as 10°.

(*b*) In myopia, in which the line MN is greater than 15 mm., the size of the angle α is less than 5°, and usually is 2°.

When the visual axis cuts the cornea upon the nasal side of the optic axis, we speak of a *positive* angle α, and when, as in some cases of myopia, the visual axis cuts the cornea on the temporal side of the axis, we speak of a *negative* angle α.

It is sometimes of importance to know the value of the angle α, since if high, it is one of the causes of apparent strabismus. When the angle is positive, the apparent strabismus is divergent, and when negative, it is convergent.

Angle γ.—This is the angle between the optic axis and the fixation axis, the line joining the point of fixation and the centre of rotation of the eye.

The angle κ.—It is not possible to measure clinically the size of the angle α, as we are unable to decide by mere inspection the exact centre of the cornea, and we, therefore, measure another angle, which is nearly the same size as the angle α and angle γ.

The angle we measure is that formed by the central pupillary line and the visual axis. This line is a normal to the cornea passing through the centre of the pupil, and cutting the optic axis at the centre of curvature of the cornea, that is, 8 mm. behind the apex of the cornea. As the centre of the pupil is to the nasal side of the centre of the cornea, this line actually cuts the cornea slightly to the nasal side of the optic axis, but, for clinical purposes, may be taken as coincident with the optic axis. The angle κ is, therefore, a little less than the angle α, and also than the angle γ.

To Measure the Angle κ.—This is conveniently measured on

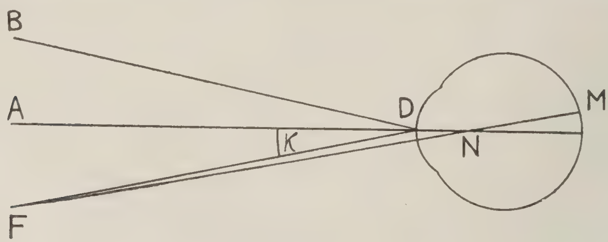


Fig. 61.

the arc of the perimeter. The visual axis is directed to the summit of the arc of the perimeter, where is placed a lighted candle, and if the visual axis and central pupillary line coincide, then the reflex of the candle will appear in the centre of the pupil, as we look at the eye over the zero mark on the arc. If however, these lines do not coincide, then will the pupillary

line pass outside or inside the visual axis. Leaving the candle at the zero mark, we move our eye along the perimeter arc until the reflex of the candle flame appears in the centre of the pupil. The reading on the arc will give double the value of the angle κ.

Let FN be the visual axis, and F the zero mark on the perimeter arc. Let AN be the pupillary line, and let B be the point upon the arc from which the image of candle flame in the cornea appears to be in the centre of the pupil. Since the angle FDB represents the sum of the angles of incidence and reflexion, it is double the value of the angle κ, which is the measure of the angle ADF, and is practically equal to the angle ANF. There is an advantage in taking a reading which is double the value of the angle required, as the angle κ is nearly always very small.

CHAPTER III

THE EYE AS AN OPTICAL APPARATUS

The eye, as an optical apparatus, may be well compared with a photographic camera, which consists essentially of a dark box, at one end of which is a strong convex lens, and at the other, a screen placed so as to receive the image of an object formed by the lens, and this image is inverted.

Having arranged the position of the screen so that a sharp image is obtained, the screen is replaced by a sensitive plate, an exposure is made, and so a picture obtained.

The mechanism of the formation of the image in these circumstances is shown by the figure.

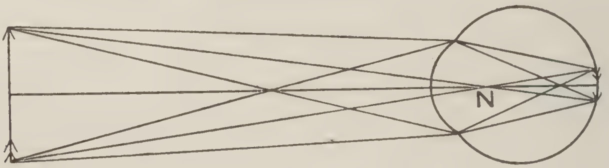


Fig. 62.—Formation of an Image by the Eye.

The eye has two lens systems, the more powerful formed by the cornea and aqueous humour, the other by the crystalline lens: the retina corresponds to the sensitive plate of the camera.

In the photographic camera, the lens has in front and behind it the same medium, namely, the air, so that the anterior and posterior focal distances are the same. The eye, on the other hand, has in front of the lens the air, whereas behind the lens is the vitreous humour, which has a refractive index greater than air, in fact, higher than that of water. As a result, the anterior and posterior principal focal distances of the eye are not equal.

The length of the eye is roughly 23 mm., which means that

the retina is about 23 mm. behind the anterior surface of the cornea. It is found that with the refractive apparatus of the eye at rest, parallel rays entering the eye come to a focus upon the retina, and so the eye is normally focussed for infinity when at rest, since parallel rays are brought together at the principal focus of lens, or of a series of lenses centred upon the same axis.

Rays leaving the retina in a parallel direction on passing out of the eye are subjected to a more powerful refraction, owing to the greater difference in value between the refractive index of the refracting system and that of the medium in which this refracting system is placed. The anterior principal focus will therefore be nearer to the cornea than the posterior, and is, in fact, 13 mm. in front of the cornea.

As the optic axis cuts the retina almost exactly at the fovea centralis, the image will fall here, and in this way, any object on the optic axis will form an image at the fovea, the spot on the retina of most distinct vision. It will be seen that for sharp images of objects at infinity, or, at any rate, at a relatively great distance from the eye, there must be an arrangement so that the retina is situated at the principal focus of the refracting system of the eye.

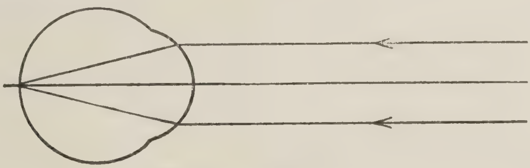


Fig. 63.—Emmetropia.

Now an object and its geometrical image are conjugate foci, and one may be replaced by the other, which means that if an object at infinity gives an image at the retina, then an object on the retina will give an image at infinity ; consequently, the retina and infinity are conjugate foci. Such an eye is called *emmetropic*, and the conjugate focus of its retina is, in ophthalmology, called its far point or *punctum remotum*.

The retina is not in all cases placed so that it coincides with

the principal focus of the refracting system of the eye, in some cases it falls short of that point, and in others is further removed from the principal focus than in emmetropia. Such variations are called *ametropia.*

If the retina falls short of the principal focus of an eye, sharp images of distant objects can no longer be formed on the retina by the refracting system at rest ; the rays will tend to come to a focus behind the retina, and there will be formed upon the retina a circle of diffusion, the cone of light, whose size depends upon the size of the pupil, being truncated. Such a condition is known as *hypermetropia.*

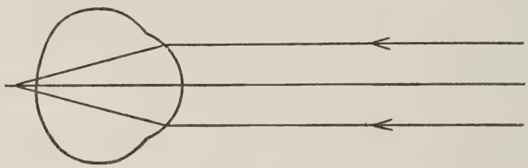


Fig. 64.—Hypermetropia.

Parallel rays starting from the retina will still come to a focus at the anterior principal focus of the eye.

Imagine a luminous area on the retina of such an eye. Rays will no longer leave the eye in a parallel direction, but in a divergent direction, and will appear to have diverged from a point behind the eye.

Now the direction of rays of light in optics is reversible, and in ophthalmology this fact is frequently used in explaining various problems that arise, for instance, in ophthalmoscopy, retinoscopy, and so on.

Let us compare this condition with the formation of images by convex lenses already considered in the optical section.

We may compare emmetropia to placing an object at the principal focus of a lens, and, hypermetropia, to placing the object nearer to the lens than its principal focus ; we saw that in such circumstances, a virtual, erect and magnified image of the object was formed on the same side of the lens as the object, and we had, in fact, made use of the lens as a simple magnifying glass.

Consequently, in hypermetropia, the conjugate focus of the retina is behind the eye, and in order that a sharp image be formed on the retina of such an eye, the object would have to be placed in such circumstances that rays leaving it are given a direction as if they diverge from the conjugate focus of the

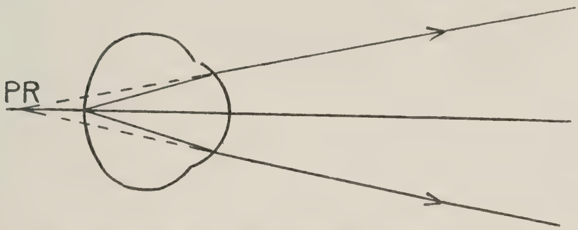


Fig. 65.—The punctum remotum in hypermetropia.

retina. This point, the punctum remotum, is virtual, and behind the hypermetropic eye.

When the retina is situated further from the refractive apparatus of the eye than its principal focus, the eye is said to be *myopic*. The effect of this is that parallel rays come to a focus on a plane anterior to the retina, and then again diverging produce circles of diffusion, and no sharp image on the retina.

Again considering the formation of an image by a convex lens, the myopic eye may be compared with the effect produced by the lens on the rays proceeding from an object placed at a distance from the lens greater than its principal focus, but less

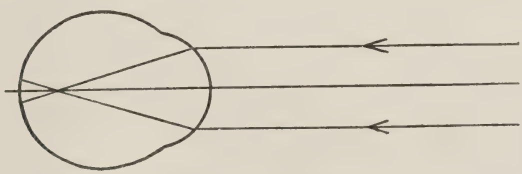


Fig. 66.—Myopia.

than infinity. A real inverted image is formed of such an object on the other side of the lens at a distance less than infinity, and so the rays emitted from a luminous area on the retina of a myopic eye form an image of the luminous area in front of such an eye, between the eye and infinity. This point

is the conjugate focus of such a retina, and is thus the punctum remotum of the myopic eye.

Recapitulating, we say, that in emmetropia the punctum remotum is at infinity ; in myopia, at a distance less than

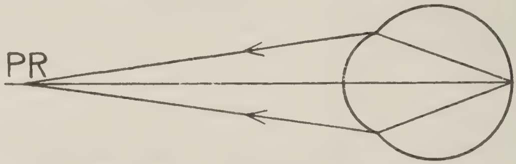


Fig. 67.—The punctum remotum in myopia.

infinity ; whereas in hypermetropia the punctum remotum is virtual, and situated behind the eye.

With the accommodation at rest, neither the hypermetropic nor myopic eye is able to see distant objects distinctly, but the myope can see an object distinctly by bringing it to his punctum remotum. The hypermetrope, with the refractive apparatus at rest, is unable to see distinctly at any distance, since he is unable to bring any object to his punctum remotum.

These errors of refraction may be corrected with lenses, which are chosen of such a power that they are able to refract parallel rays to such a direction that they appear to diverge from or converge to the punctum remotum of the defective eye.

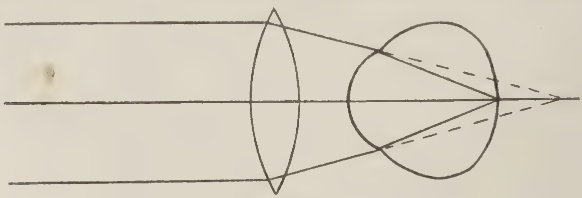


Fig. 68.

In the hypermetropic eye, if we were able to refract parallel rays so that they appeared to diverge from the virtual punctum remotum, then this point being the conjugate focus of the retina, the rays would come to a focus on the retina.

This power is possessed by a convex lens, and it is necessary to choose a convex lens whose focal length is equal to the distance of the punctum remotum behind the cornea.

For example, taking a hypermetropic eye whose punctum remotum is 1,000 mm. behind the cornea ; this is the focal length of a + 1 D lens, consequently a + 1 D lens placed in contact with the cornea would cause parallel rays to converge towards this point, and if such a lens could be worn in contact with the cornea it would enable such an eye to see distant objects clearly. Owing to the fact that lenses are worn about 15 mm. in front of the eye in spectacle frames, the lens chosen should have a focal length of 1,015 mm., and so would be a little less than 1 D in value.

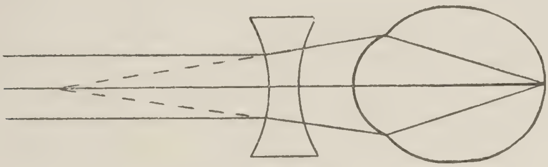


Fig. 69.

Similarly in myopia, parallel rays must be given a divergence such as they would have if proceeding from the punctum remotum, the conjugate focus of the retina. Such a power is possessed by a concave lens, so that a myope, whose punctum remotum is 1,000 mm. in front of the cornea will require a 1 D concave lens, but owing to the fact that the lens cannot be worn in contact with the cornea, it must have a slightly shorter focus, namely, about 985 mm., and must, therefore, have more than 1 D value.

We have treated errors of refraction so far as if they were constantly due to variations in length of the globe. Such errors are called axial errors, and it is true that the majority of examples are due to this cause. Errors may, however, be caused by variations in the refractive indices of the refracting media, so-called *index* errors, or by variations in the curvature of the refracting surfaces, so called *curvature* errors. These will be considered in a later section, but there is one common curvature error that must be considered here.

Those portions of the refracting surfaces of the eye that are exposed in the pupillary area have been considered so far as if

they were spherical, so that if planes pass in all directions in the axis cutting the curved surfaces, then the figures caused by these sections show similar curves.

It is rarely that all these curves are found to be exactly similar, but in various meridians the curvature varies. This condition is called *astigmatism*, and is usually situated in the cornea. We speak of regular and irregular astigmatism, but it is only of regular astigmatism that we shall speak here.

Astigmatism is called regular when the different meridians which cut the refracting surface present in their alterations of curvature a gradual change in passing from one meridian to another, the curvatures that are most different being at right angles to each other. The top of an egg is spherical, but a portion of the shell removed from the side of the egg would correspond to the astigmatic cornea.

The result of this defect is that the eye has two puncta remota, the retina two conjugate foci. Consequently, in no relative position of eye and object is distinct vision obtainable, and the condition cannot be corrected by spherical glasses. If we suppose one meridian to be emmetropic, and the other hypermetropic, then what is required is a lens of such form that it will correct the hypermetropic meridian without interfering with the optical condition of the emmetropic meridian. We therefore use for the purpose a cylindrical glass, and place it in such a position that the curved surface of the cylinder coincides with the less curved surface of the cornea.

Accommodation.—It is a matter of common experience that we are able to see distinctly distant objects, and also objects placed at different distances from the eye, ranging from infinity up to within a few centimetres of the eye.

This power is called the accommodation of the eye for distances.

The nearest point at which distinct vision is possible is called the *punctum proximum*, the farthest point the *punctum remotum*, and the distance separating these points is called the *range of accommodation*, which is found to vary with age.

Since distinct vision is possible at this variety of distances,

it means that a sharp image of the object viewed is formed upon the retina, in other words, that the retina is placed at the conjugate focus of these varying points, so that sharp images are formed, and not circles of diffusion.

Taking the photographic camera for comparison, when the screen is placed at the principal focus of the lens, images of distant objects are formed there which are quite sharp, but as the object is brought nearer to the camera, so its image is formed farther and farther behind the screen, which is now no longer at the conjugate focus of the object, and experience shows that to obtain a sharp image the screen must be moved farther and farther back as the object approaches the lens. This is well shown in the diagrams in earlier pages dealing with the formation of images by a convex lens.

Obviously, if a sharp image of an object at varying distances is to be formed on the retina, some change must take place in the eye.

There are several ways in which this might be brought about, and each has had, at different times, some measure of support.

1. The eye might alter in length by the backward displacement of the retina, as we see in the photographic camera. This was disproved by Young, by an experiment upon his own eyes. Young had a high degree of myopia and, as a consequence, prominent eyes; therefore, by turning his eye strongly inwards, he was able to bring the posterior surface of the globe comparatively near to the surface. He took a pair of dividers, and fastened to each point a small bureau key, and then placed one over the apex of the cornea, and the other over the macula, by driving it back into the orbit. He knew when the key ring was over the macula, by the coincidence of the resulting phosphene with his visual axis. Although, by firmly applying these rings, elongation of the globe could be abolished, nevertheless, he could still accommodate, and there was no alteration of the phosphene, such as would be caused had the eye elongated and so greater pressure been exerted by the eye upon the confining rings.

2. The curvature of the cornea might be increased, and so its refractive power. Young again disproved this by the observation that he could still accommodate while the eye was submerged in water, which would abolish all refractive power in the cornea by its being bounded posteriorly and anteriorly by media of equal refractive indices. At the time Young made the experiment, his amplitude of accommodation was about ten dioptres.

3. The crystalline lens might advance, but an advance of the lens, even as far as the posterior surface of the cornea, could not effect the increase in the refractive power of the eye necessary for the clear vision of near objects. Tscherning calculated that the lens would have to advance 10 mm. in order to give the full amplitude of accommodation to the eye.

4. Scheiner had observed that the pupil contracted during accommodation, and suggested that the diminution of the pupillary opening produced the clear image necessary in near vision by cutting off marginal rays; but there is no regular alteration in the size of the pupil during accommodation.

5. There remains the possibility that the curvature of the lens alters during accommodation, increasing as the eye is focussed for near objects.

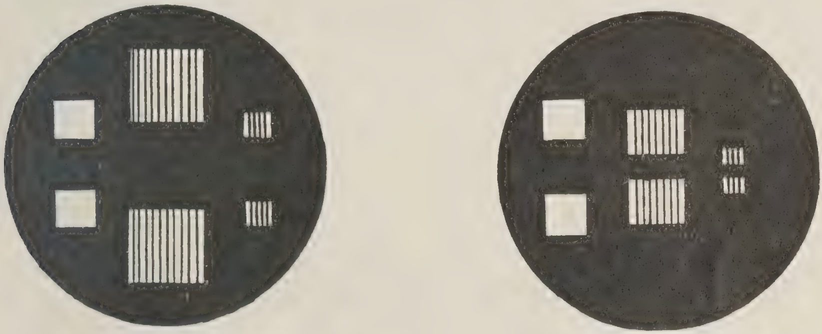
Young showed that this was the probable reason, by proving that people who had had their lenses removed by operation for cataract were no longer able to accommodate, but he was unable to formulate a hypothesis to explain the mechanism.

The alteration that occurs in the curvature of the surfaces of the crystalline lens, of the anterior surface more especially, can be demonstrated by observing alterations in size of the Purkinjé figures formed by the reflecting surfaces of the media of the eye. The original observations were made by Langenbeck and Cramer, on the anterior surface of the lens, and later and independently, by Helmholtz, who also observed a slight alteration in curvature of the posterior surface of the lens.

As explained in the section on ophthalmometry, the curvature of a reflecting surface can be calculated from the size of the

image of an object of known size, the curvature of the reflecting surface being greater the smaller the image.

With his phakoscope, Helmholtz was able to show that if the images of two luminous squares be reflected from the eye, then not only are the two images from the front of the lens reduced in size on accommodation, but they are brought together. In a very much less degree the images from the posterior surface of the lens are reduced in size and approximated.



The images with the accommodation at rest. FIG. 70. The images during accommodation.

Helmholtz was able to show that the radius of curvature of the anterior surface of the lens was reduced from 10 mm. to 6 mm., of the posterior surface from 6 mm. to 5·5 mm.; at the same time the thickness of the lens increased from 3·6 mm. to 4 mm.

On watching an eye looking alternately at far and near objects, it will be seen that the plane of the iris is bulged forward during accommodation, and that whereas at rest the aperture of the pupil is seen as a long black line, in near vision the margin of the iris is further forwards and the pupil narrowed. Helmholtz states that there is displacement forwards of the anterior surface of the lens from 0·36 to 0·44 mm.

Hess has shown that in forcible accommodation, or after the use of physostigmine to produce a spasm of the ciliary muscles, there is a displacement of the lens, due to a fall by its own weight, the direction depending upon the position of the head.

This displacement has been accurately measured, and may vary from 0·25 to 0·30 mm. in forced voluntary accommodation, to 1 mm. under the action of physostigmine.

In eyes that had a deformity of the iris after the operation of iridectomy, Hess showed that there was a bulging of the ciliary processes towards the equator of the lens, without thickening, showing that the ciliary processes advanced towards the cornea.

Hensen and Völkers ran a fine needle into the equator of a freshly excised human eye, and upon stimulating the ciliary processes were able to show a forward displacement of the choroid.

The appended figure after Beer shows the effect of accommodation in the cat upon two needles passed into the anterior part of the choroid.

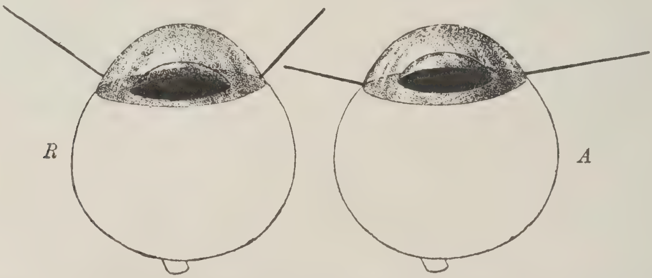


FIG. 71.—Accommodation in the Cat's Eye. *R*. Distance. *A*. For near vision. (After Beer.) Two needles have been passed through the edge of the cornea into the ciliary bodies, to show forward movement of the latter during accommodation.

Further evidence that accommodation is brought about by contraction of the ciliary muscle is provided by the anatomical appearances of the ciliary muscle in hypermetropia and myopia. In hypermetropia accommodation is used not only when viewing near objects, but constantly for distant vision, so as to correct the error of refraction. Here the muscle is found hypertrophied and larger than in emmetropia, and very much larger than the ciliary muscle of the myopic eye, in which accommodation is rarely required, and which is less developed than in emmetropia (Fig. 72).

The Mechanism of Accommodation.—According to Helmholtz the lens is an elastic body, which, upon removal from the eye, takes on a more globular form, thus showing that in the eye it is subject to some mechanism whereby it is constantly kept in a

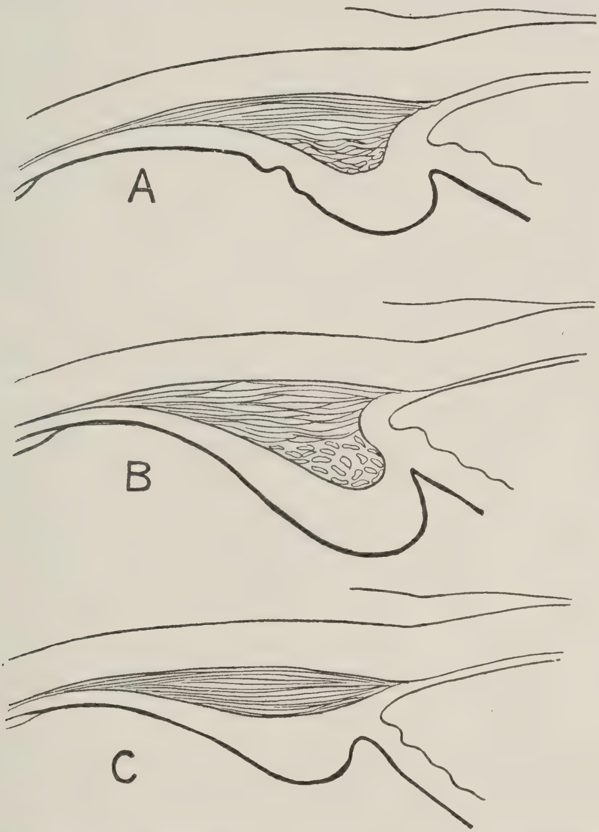


Fig. 72.—The Ciliary muscle in (A) Emmetropia, (B) Hypermetropia, (C) Myopia. (Fuchs).

less globular form, and more flattened antero-posteriorly. The lens is kept in place in the eye by a series of fibres, the suspensory ligament, attached around its equator, and to the ciliary processes. These fibres consist of three groups, called respectively pre-equatorial, that pass from the ciliary processes to the anterior surface of the lens ; equatorial, passing to the

equator of the lens; and post-equatorial, passing to the posterior capsule of the lens.

On their outer surfaces the ciliary processes contain the ciliary muscle, which is about 3 mm. broad and consists of smooth muscle fibres. The outer part, the muscle of Brücke, arises from the sclera just behind the canal of Schlemm, and passing backwards is inserted into the anterior part of the choroid. It is described as consisting of two parts, an outer meridional portion parallel with the inner surface of the sclera, and further inwards, a more conspicuous portion forming the main mass of the muscle, the radial portion, whose bundles diverge radially towards the inner part of the ciliary body. The innermost portion, the muscle of Müller, appears in meridional sections cut across the direction of its fibres.

When the ciliary muscle contracts, we have seen that the anterior part of the choroid is drawn forwards, and also that the apices of the ciliary process are approximated, the radial and meridional fibres drawing forwards the choroid, and also approximating the ciliary processes, whereas the main action of the circular fibres is to approximate the apices of the ciliary processes. The result will be a relaxation of all the fibres of the suspensory ligament, allowing the anterior surface of the lens to become more convex in the direction in which there is little resistance, whereas the posterior surface of the lens alters little in shape owing to the support of the much more solid vitreous.

The slackening of the fibres of the suspensory ligament shown by Hess in his observations upon the lateral displacement of the lens during accommodation, and the forward movements of the apices of the ciliary bodies are both at variance with Tscherning's hypothesis. This supposes that the superficial fibres of the ciliary muscles draw the choroid forwards so as to prevent backward displacement of the lens while the deeper fibres draw the zonule backwards and outwards so as to flatten the peripheral parts of the anterior surface of the lens and allow the central and pupillary area to increase in curvature.

During accommodation the ciliary muscle thickens, the ciliary processes advance and approach the equator of the lens without increasing in size, the anterior, and to a less degree, the posterior surface of the lens increases in curvature, the angle of the anterior chamber is deepened and made more obtuse, and

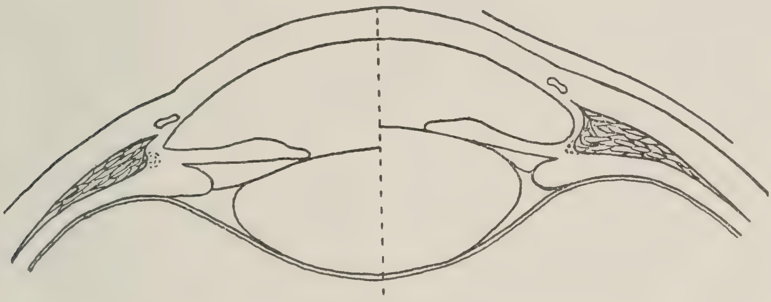


FIG. 73. (Luciani.)

the pupillary portion of the anterior chamber is reduced in depth.

Accommodation is synchronous and equal in both eyes, and extends throughout the whole muscle. Hess and Neumann found that normal eyes can only compensate a difference in refraction between the two, of 0·12 D.

Taking the reduced eye, the following table gives the position of the image with different distances of the object (Luciani) :

Distance of object.	Position of image.	Distance of object.	Position of image.
∞	20·00 mm.	0·50 m.	20·62 mm.
5 m.	20·06 mm.	0·25 m.	21·27 mm.
1 m.	20·30 mm.	0·125 m.	23·57 mm.

Accordingly, when the object is at a distance of 5 m. from the reduced eye, the image is only moved back 0·06 mm. The sensitive layer of the retina is 0·06 mm. in thickness, so that it

follows that at a distance of 5 m. the emmetropic eye need not use its accommodation for distinct vision.

This fact is made use of in determining the minimum distance at which test types for measuring the acuity of vision with the eye at rest are used.

Scheiner's Experiment.—This consists in looking at a pin at different distances from the eye through two small holes in a card, so close together that their distance one from the other is less than the diameter of the pupil.

This card is placed just in front of the pupil, as near to the eye as is conveniently possible ; a pin's head is then held in front of the card and moved to various distances from the eye. When held at a distance, one image of the pin's head is seen. When held very near to the card, two indistinct images of the pin's head are seen. The nearest point at which a single distinct image of the pin's head is seen is the punctum proximum of the eye.

The explanation of the experiment is as follows :

Take a biconvex lens, a candle, a screen, and a small disc in which two small holes have been made, and let them be arranged as in the diagram.

Let O be the candle flame, e, f, the holes in the card, placed before the biconvex lens, and r the screen which corresponds to the retina. If the screen be not at the focus of the lens two

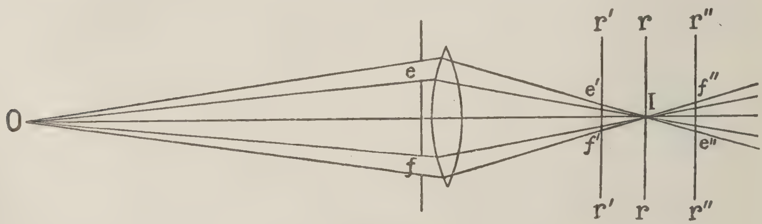


Fig. 74.

images will be seen, if at r', e' f', if at r'', e'' f'', and by occluding one of the holes and observing which image is obliterated, we are able to decide whether the screen is in front of or behind the focus of the lens.

Clinically the punctum proximum is measured by testing and measuring the distance at which the smallest type on the reading chart can be read. The measurement is made from the anterior focal plane of the eye, that is, 13 mm. in front of the cornea.

Another method is by the use of concave lenses, such as are found in the box of lenses used in testing the refraction of the eye. Taking an emmetropic eye, or one rendered emmetropic by suitable lenses, which can, therefore, see objects at infinity with the accommodation relaxed, we use as our test object the small letters of the distant test type. We then place in front of the eye, successively, concave lenses of increasing power, and so determine the lens of highest dioptric value that the eye can overcome by an effort of accommodation and still read clearly the small type. The focal length of such a lens represents in centimetres the distance of the punctum proximum from the eye.

The Measurement of Accommodation.—The punctum remotum of an eye is the conjugate focus of the retina with the accommodation relaxed, the punctum proximum the conjugate focus of the retina with the accommodation exerted to its utmost. The distance between these two points is the distance over which the eye is theoretically capable of focussing objects, and is known as the *range of accommodation*. Thus an emmetrope of twenty years whose punctum remotum is at infinity and whose punctum proximum is at 10 cm. from the eye, has a range of accommodation which is infinite. A myope of twenty years whose punctum remotum is at 10 cm., that is, with an error of refraction of 10 dioptres, and whose punctum proximum is at 5 cm., has a range of accommodation of 5 cm. A hypermetrope of twenty years whose punctum remotum is 20 cm. behind the eye, that is, with an error of refraction of 5 dioptres, and whose punctum proximum is at 20 cm., has a range of accommodation which is infinite; the region of accommodation, however, differs from that of an emmetrope of the same age in that the punctum proximum is 10 cm. further from the eye.

Although interesting as showing the distance over which the eye is theoretically capable of accommodating, this measure gives no indication of the power of accommodation of the eye. The power of accommodation is expressed by the difference between the refracting power of the dioptric mechanism of the eye at rest, that is, when focussed for its punctum remotum, and that when its accommodation is exerted to its utmost, that is, when focussed for its punctum proximum. It represents the dynamic refracting power of the eye, and is known as the *amplitude of accommodation*.

Let e dioptres be the refracting power of an eye focussed for infinity. In order that such an eye may see clearly an object at a point P at a distance of $\frac{1}{p}$ metre, it will be necessary to place before it a lens which will render parallel rays from the point P, that is, a lens of p dioptres; or, alternatively, the eye must make an effort of accommodation which increases its refracting power by p dioptres. Therefore, the refracting power of the eye focussing the point P at $\frac{1}{p}$ metre away, will be $e + p$ dioptres.

Similarly, the refracting power of the eye focussed for a point R, at a distance $\frac{1}{r}$ metre, will be $e + r$ dioptres.

If the points P and R be the near and far points of the eye respectively, then, according to the definition, the difference between the refracting power of the eye, when focussed for P, and that, when it is focussed for R, will give the amplitude of accommodation (a). That is,

$$\begin{aligned} a &= (e + p) - (e + r) \\ &= p - r. \end{aligned}$$

In the case of the emmetrope of twenty years with the punctum proximum at 10 cm. or $\frac{1}{10}$ metre from the eye, $\frac{1}{r} = \infty$ and $r = 0$.

Therefore
$$\begin{aligned} a &= p - r \\ &= 10 - 0 = 10 \text{ D}. \end{aligned}$$

In the myope of twenty years with the near point at 5 cm. or $\frac{1}{20}$ metre, and the far point at 10 cm. or $\frac{1}{10}$ metre from the eye:

$$\begin{aligned} a &= p - r \\ &= 20 - 10 = 10 \text{ D.} \end{aligned}$$

In the hypermetrope of twenty years with the near point

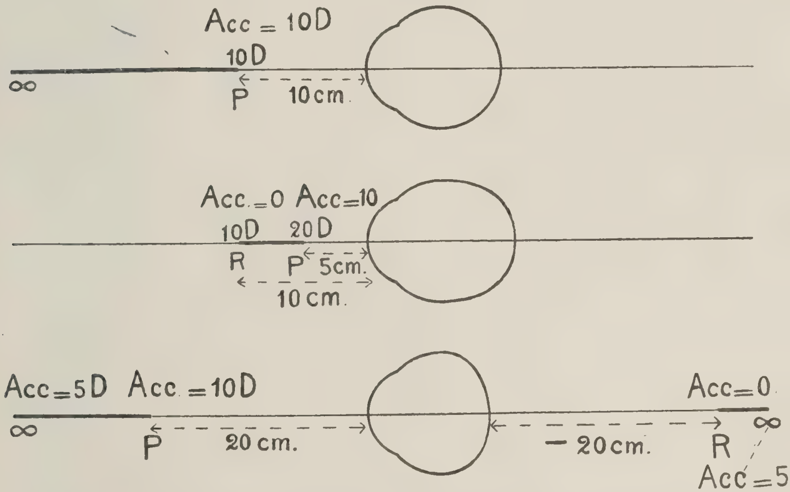


FIG. 75.—Diagram showing that although the Range of Accommodation varies, the Amplitude is the same in an Emmetrope, Myope and Hypermetrope of the same age.

at 20 cm. or $\frac{1}{5}$ metre, and the far point at $-$ 20 cm., or $-\frac{1}{5}$ metre from the eye:

$$\begin{aligned} a &= p - r \\ &= 5 - (-5) = 10 \text{ D.} \end{aligned}$$

It is obvious that, although these three individuals have very different ranges of accommodation, the amplitude of accommodation is the same in all three at the age of twenty years.

This may be shown graphically by the diagram overpage Fig. 75.

Changes of Accommodation with Age.—The amplitude of accommodation diminishes regularly with age, as is shown by a

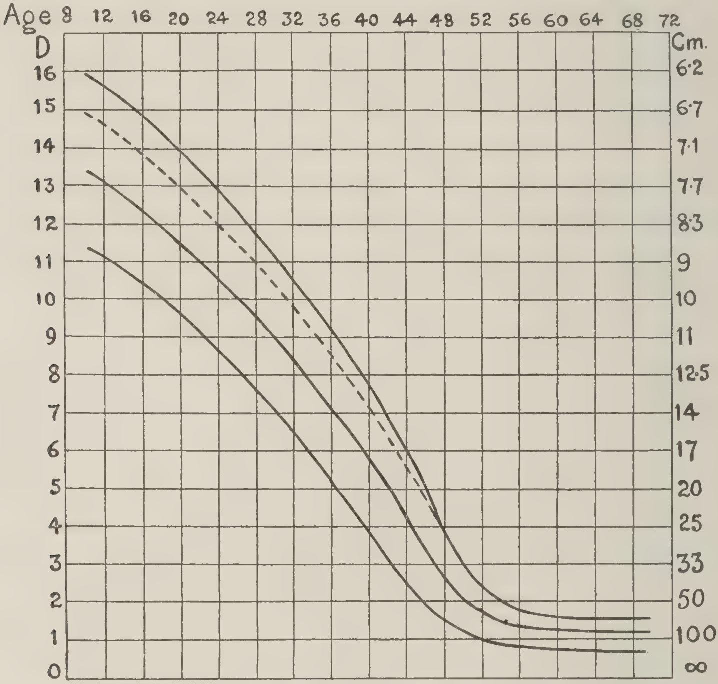


Fig. 76. (Duane.) D represents the dioptric strength of the lens which, placed at the anterior principal focus of the eye, corresponds to the change in refractive power of the cystalline lens in extreme accommodation. Cm represents the focal length of this lens.

recession of the punctum proximum. This gradual decrease is due to a progressive diminution of the elasticity of the lens, which becomes harder as age increases, forming a nucleus, so that for a given effort of accommodation there is less response in the lens in the direction of increase of curvature of its surfaces. It is unlikely that this loss of accommodative power is due to loss of muscle power, since it has its onset in childhood, at a time when muscular power elsewhere in the body is increasing.

The thickness of the lens diminishes with age, its curves diminish, and so the static refraction of the eye alters in comparison with the condition in youth.

Vision through a Lens.—We have seen that in order to correct the various errors of refraction lenses of various kinds are used, and the type of lens can easily be determined. The power of the lens chosen is one that will cause parallel rays to appear to diverge from or converge to the punctum remotum of the eye, the point in space conjugate to the retina.

When a near object is viewed through a lens a virtual image of the object is seen, and the size of the image can be calculated. It is important to know what effect the spectacle lens has upon the size of the retinal image, and we shall see that this depends upon the distance from the eye at which the lens is placed.

Formation of a Retinal Image by the Eye.—Given the two principal planes of the eye E_1E_2, and the anterior and posterior

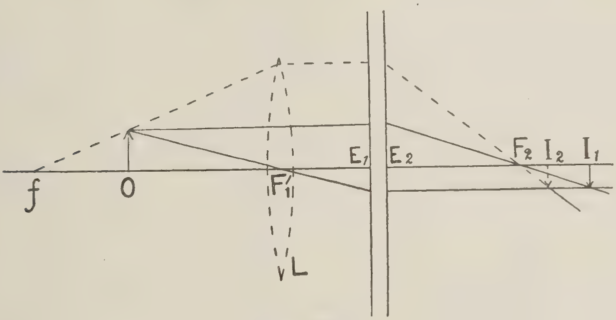


Fig. 77.

principal foci F_1F_2, we can construct the image formed in the eye of an object O upon the optic axis. As usual we will take one ray parallel to the axis, which, after refraction, will pass through the posterior principal focus, and another ray, which, passing through the anterior principal focus, will, after refraction, continue its course in a direction parallel to the optic axis. At the point where these rays intersect will be found the image of the object, I_1.

The size of the image is determined by the distance between the optic axis and the ray parallel to it, and so the size of the image at the anterior principal plane is equal to that formed within the eye.

If the magnification be M, then :

$$M = \frac{I}{O} = \frac{F_1E_1}{O\,F_1}.$$

The Effect of a Lens at the first Focal Plane of the Eye.—Let a lens be placed so that its optic centre coincides with the anterior principal focus of the eye, Fig. 77, let $F_1 f$ be its focal length. Then a ray drawn from f through the upper extremity of the object O will be parallel after refraction by the lens, and so will be refracted by the dioptric apparatus of the eye through the posterior principal focus. The ray passing through F_1 will be unaffected by the lens, and so the image is formed at I_2. It is

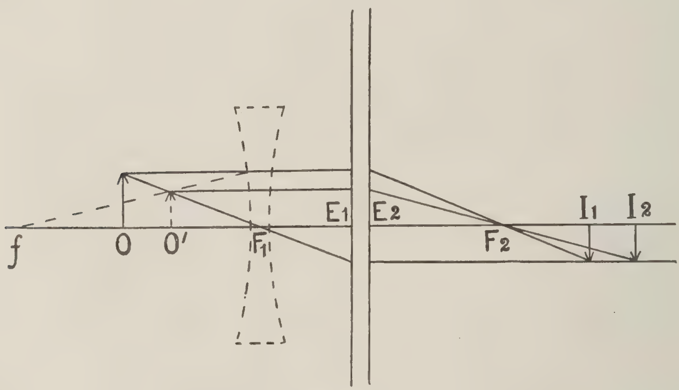


Fig. 78.

thus seen that a lens placed at the anterior principal focus of the eye does not affect the size of the image, but only moves it forwards in the instance in which a convex lens is used.

Diagram Fig. 78 will show that in the case of a concave lens, the image of the object is moved further back along the optic axis.

If the image I_1 is formed behind the retina, then, so that the eye may see it clearly, accommodation is necessary. Now accommodation by causing an alteration in the power of the refractive media diminishes both the anterior and posterior focal distances, and so the magnification as expressed in the equation $\frac{F_1E_1}{O\,F_1}$ is diminished.

If the eye be emmetropic, that is, the retina be at F_2, then, for the object O to be seen without accommodation through the lens, it must be placed at f, the principal focus of the lens.

The Effect of a Lens placed beyond the First Focal Plane of the Eye.—Let a lens L be placed between the object O and

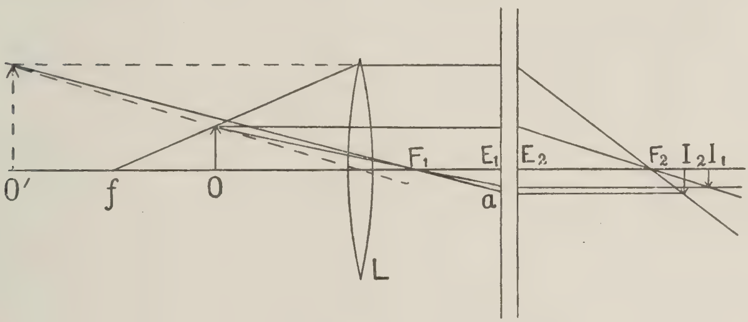


FIG. 79.

the first focal plane of the eye F_1. A virtual image of O will be formed at O′ according to the rules we have seen that apply to convex lenses.

In Fig. 79 I_1 is the image of O formed by the refractive apparatus of the eye alone, and I_2 is the image of O′, that is, the image of O after the convex lens L has been interposed. I_2 is obviously larger than I_1.

Thus the size of the intraocular image increases if a convex lens is placed slightly in advance of the anterior principal focus of the eye.

In the case of a concave lens (Fig. 80) placed beyond the

anterior focal plane of the eye, the size of the intraocular image is reduced.

We see then that :

1. A lens placed at the anterior focal plane of the eye will not affect the size of the retinal image ; if convex it will cause the image to move forwards, and if concave, backwards.

2. If the lens be convex, and is moved away from the anterior

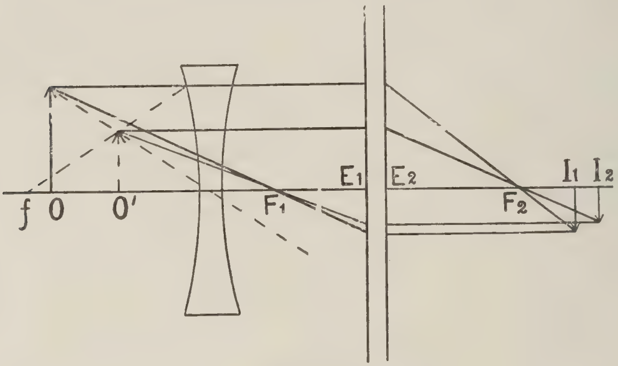


Fig. 80

focal plane, the image is increased in size and moved forwards. The image will decrease in size and be moved backwards if the lens is moved from the anterior focal plane towards the eye.

3. If the lens be concave the image will decrease in size as the lens is moved beyond the anterior focal plane of the eye, and increase as it is moved from the anterior focal plane towards the eye.

The anterior focus of the eye is at a distance of 13·7 mm. in front of the cornea, and, owing to the projection of the lashes, spectacle lenses are nearly always worn in advance of this point.

In hypermetropia, as we have seen, the correcting lens, if worn at the anterior focus of the eye, merely moves the image forwards to the retina without altering its size. An effort of accommodation will then produce an image the same size as in an emmetropic eye focussed for the same near object.

However, if the hypermetropic eye sees a near object merely by the use of its accommodation, the retinal images will be

smaller than in emmetropia, owing to the fact that both its anterior and posterior focal distances have been reduced.

In myopia the concave lens at the anterior focus of the eye merely throws the image further back without altering its size as compared with emmetropia. An effort of accommodation in an eye corrected for distant vision will produce a retinal image the same size as that in an emmetropic eye. As the lenses are usually worn in advance of the anterior focus of the eye the retinal image is reduced in size, a matter of importance when the myopia is of high degree, and, consequently, the lenses worn of high power.

In presbyopia, when all power of accommodation has been lost, a lens placed at the anterior focus of the eye will, if of suitable power, allow reading at the focal distance of the lens. If, with the book at a fixed distance, the lenses be moved forwards, then the image will fall behind the retina, and distinct

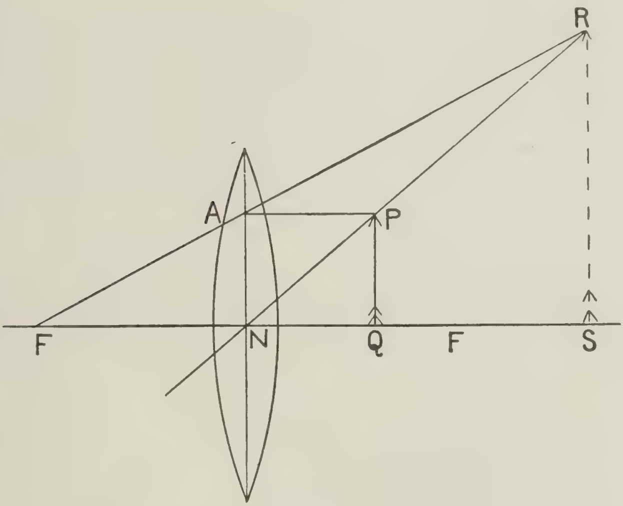


Fig. 81.

vision will not be obtained. The image, however, will be increased in size, so that a presbyopic patient with lenses too weak for use at ordinary reading distance will place the glasses

further down his nose, so as to make up in size of retinal image what he has lost in distinctness.

Vision through a Magnifying Glass.—When an object is placed nearer to a convex lens than its principal focus there is produced a virtual, erect and magnified image of the object on the same side of the lens further removed than its focal distance, which will be the object for an eye placed behind the lens (Fig. 81).

The apparent size of an object depends upon the angle that it subtends at the nodal point of the eye, and the nearer the object be brought to the eye, the larger the angle it subtends, the larger is the retinal image, and the larger it appears.

There is a limit to which this method of magnification can be carried, as after a certain point the object becomes so indistinct that its details can no longer be clearly seen. The object has been brought nearer to the eye than its own least distance of distinct vision.

In the diagram it will be seen that the angle subtended at N by the object and image is the same, so that if the lens be held very near to the eye, at its anterior focus, the object and image will subtend equal angles at the eye. If it were possible to see the object in its *actual* position without the lens it would appear of the same size as when seen through the lens, but at this distance it would not be seen clearly, as it is within the least distance of distinct vision. The lens, therefore, is used to remove the object beyond the least distance of distinct vision, and at the same time retain unaltered the angle it subtends at the eye, and thus the actual size of the image upon the retina.

CHAPTER IV

ERRORS OF REFRACTION

Myopia.—Myopia is that state of refraction of the eye in which, with the accommodation at rest, parallel rays come to a focus in front of the retina, that is, the retina is placed behind the principal focus of the eye.

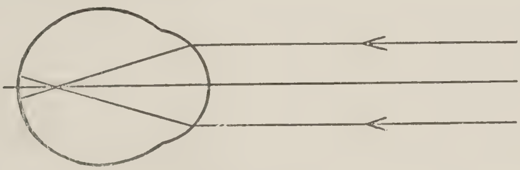


FIG. 82. Myopia.

The result is that parallel rays that have come to a focus have again become divergent, and so when they cut the retina they do not produce a point, but a circle of diffusion.

If we imagine the rays from a luminous point upon the retina of a myopic eye, their divergence will not be so great as that of rays that have originated at the principal focus, and the result will be that the dioptric apparatus of the eye, which is able to render rays that have proceeded from the principal focus parallel, will render less divergent rays convergent, so that they will meet between the eye and infinity.

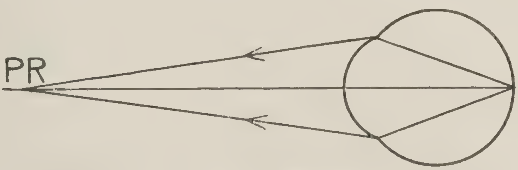


FIG. 83. The Punctum Remotum in Myopia.

Here, then, at PR, will be formed the geometrical image of the luminous point on the retina, which is also the conjugate focus

of the retina of the myopic eye, and this point is spoken of as the punctum remotum, the point for which the myopic eye is focussed in the condition of static refraction.

If now, reference be made to the diagrams showing the formation of images by convex lenses, it will be seen that a myopic eye may be compared to the condition in which the object is placed at some point further from the lens than its principal focus (but less than twice its focal length), the image being formed at a point whose distance from the lens is less than infinity.

As rays of light in optics are reversible, it means that an object placed at a point conjugate to the retina, on one side of the eye, less than infinity, will give a sharp image upon the retina, of the myopic eye. Although the myopic eye is unable to form sharp images of distant objects, rays of light from which are parallel, nevertheless if the object be placed at the punctum remotum then a sharp image will be formed on the retina.

We are thus able to consider the means whereby this error of refraction may be corrected, since if parallel rays could be given a direction as if they proceeded from the punctum remotum of the eye, then these rays would come to a focus upon the retina, and the eye would be fitted for distant vision.

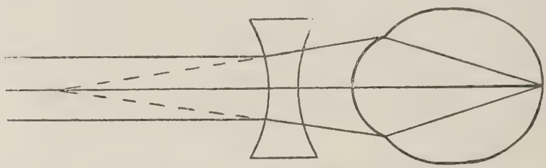


Fig. 84. The use of a Concave Lens to correct Myopia.

This will be seen in Fig. 84, in which a concave lens placed at the anterior principal focus of the eye has its principal focus at the punctum remotum so that it causes parallel rays to diverge as if they came from this point.

Our definition of myopia has merely stated that the retina is behind the principal focus of the eye, that is, that the eye is

adapted for finite distance only. It has not stated what the causes of the condition may be.

The main causes are two :

(*a*) There may be an actual lengthening of the eye as compared with the emmetropic eye, the power of the refractive apparatus remaining the same, so-called *axial myopia.*

(*b*) The length of the eye may be the same as that met with in emmetropia, whereas the refractive apparatus is relatively too powerful, *refractive myopia.*

The result in either case is the same.

Axial Myopia.—The commonest cause of myopia, especially of the highest degrees, is lengthening of the globe, and it has

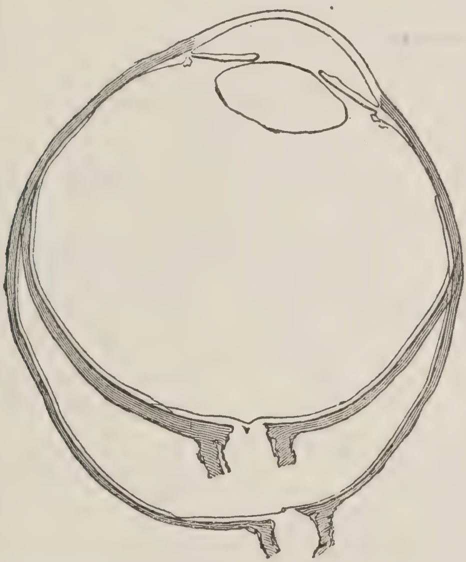


FIG. 85.—Horizontal sections of Emmetropic and Myopic Eyes from the same patient superposed, showing the identity of the pre-equatorial regions. (Heine.)

been proved anatomically that this lengthening affects the posterior part of the eye and its surroundings, that part behind the equator, the eye in front of the equator being quite normal.

It follows from this that, in marked degrees of myopia, the

eye is unduly prominent, and less mobile than the emmetropic eye, owing to its larger size. If the eye be strongly rotated towards the nose, and at the same time the lids be drawn outwards, the flattened curve of the sclera can be seen as it passes from the equator towards the posterior pole.

Refractive Myopia.—*Curvature Myopia.*—This may be produced by an increase in the curvature of the cornea, either congenital, as met with in astigmatism, or acquired, as is seen in conical cornea. An increase in the curvature of the surfaces of the lens would produce the same result.

Index Myopia.—Myopia will result from :

(*a*) An increase in the index of refraction of the cornea or aqueous.

(*b*) An increase in the total index of refraction of the lens caused either by an increase in the index of refraction of the nucleus, or a decrease in the index of refraction of the cortex. The myopia so often seen as an early symptom of senile cataract is due to an increase of the refractive index of the nucleus.

(*c*) A low index of refraction of the vitreous thereby increasing the refractive power of the lens.

The Measure of Myopia.—The commonest cause of myopia is an increase in the length of the eye, an increase of 1 mm. causing 3 dioptres of myopia ; hence the greater the length of the eye the higher the degree of myopia.

The distance between the punctum remotum and the cornea of the myopic eye can be measured, and it is the greatest distance at which small type may be read when the accommodation is at rest. When making this measurement, we choose as one point the anterior principal focus of the eye, a point 13·7 mm. in front of the cornea, because, as we shall see, it is near here that the lens correcting the myopia is usually worn.

A concave lens has the property of causing parallel rays to appear to diverge from its principal focus, so that if a concave lens be placed at the anterior principal focus of the eye, so as to cause parallel rays to diverge from the punctum remotum of the eye, this point must coincide with the principal focus of

the lens. If, therefore, we know the distance of the punctum remotum from the anterior principal focus of the eye we can easily deduce the dioptric value of the lens which will correct the myopia. We express the degree of myopia in dioptres, so that an eye whose punctum remotum is 50 cm. from its anterior principal focus is said to have 2 dioptres of myopia and so on.

As our measurements are made, not from the cornea, that is, the principal point of the eye, but from the anterior principal focus, the dioptric value of the lens correcting the myopia is slightly in excess of the actual myopia.

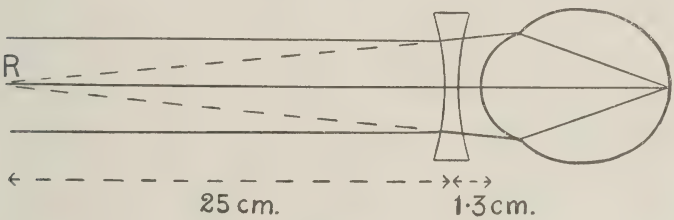


FIG. 86.

Suppose the punctum remotum to lie 26·3 cm. from the cornea, then the lens, placed in contact with the eye, which would correct the myopia would have a dioptric value of $\frac{100}{26 \cdot 3} = 3 \cdot 8$ D, but as the lens is placed 13 mm. in front of the cornea, its dioptric value is $\frac{100}{25} = 4$ D. This also shows that the further the correcting lens is removed from the eye, the greater must be its dioptric value, and also explains that if a myopic patient is wearing lenses that undercorrect his degree of myopia, he can, by moving the glasses nearer to his eye, cause the principal focus of the lens to come nearer to his punctum remotum, thereby obtaining the same effect as from a stronger lens placed at the anterior principal focus of the eye.

It is only in the highest degrees of myopia that the difference between the theoretical and practical amount of myopia is

of any importance, as the above example shows, but a theoretical degree of 20 D will require for its correction a lens of 27 D placed at the anterior principal focus.

Development and Course of Myopia.—The newly born are almost exclusively hypermetropic, the hypermetropic eye being apparently the immature eye ; as age increases the eye becomes less hypermetropic, so that by the age of ten years the eye should have become emmetropic.

The proportion of patients that are myopic increases gradually until the twentieth year, by which time about 20 per cent. of the population are myopic, a figure that remains constant for all ages, so that at the seventy-fifth year the number of patients that suffer from myopia is still 20 per cent.

The onset of myopia is, therefore, coincident with the period of growth, and during that period those who have become myopic at an earlier age continue to become more myopic until the age of about twenty-two years, when growth ceases. This increase in myopia may be different in the two eyes.

Myopia is commoner in towns than in the country, especially in the higher schools, and also among those who constantly use their eyes for small objects, such as print, and especially among embroiderers, tailors, compositors, and so on, so that myopia has come to be considered as due to the strain necessitated by near work. It is, however, doubtful if the use of the eyes for near work is the cause of myopia, although there is little doubt that upon eyes already myopic, near work has a deleterious effect.

It must be remembered that the larger proportion of myopic individuals in the higher schools coincides with the accumulation of the number of cases of myopia that have originated during the years that have elapsed between birth and about sixteen years of age, that is, during the period of greatest growth, and further, that although all eyes up to about sixteen years of age have been subject to the same strain, only a small proportion have become myopic. The finding of so many cases of myopia among those occupations requiring the use of the eyes for near objects, may be explained by the fact that myopes frequently

choose such callings, their sight not being sufficiently good for occupations requiring acute distant vision.

The high degrees of myopia occur equally among all grades of the population, and are met with in the same proportion among those who use their eyes for near objects and those who are illiterate or who never use their eyes for near work at all. From this it has been argued that the basis of myopia is congenital, a comparative weakness of the coats of the eye in relation to the intraocular pressure, which would also explain the continued increase in degree during the period of growth, and in certain less common cases, throughout life. Heredity also plays some part, and frequently myopia is found in more than one generation, and in several members of the same family.

There is a predisposition to myopia, shown more especially in its hereditary character, the child being born hypermetropic, but developing myopia later on. The influence of near work upon its increase has received certain explanations which are not correct, among them being the effect of the act of accommoda-tion. Now, accommodation in the myopic eye is less used than in any eye condition, and very much less than in hypermetropia, in which the ciliary muscle is hypertrophied, whereas in myopia it is smaller than in emmetropia. Again, accommodation does not affect the intraocular pressure, and further, it only affects the choroid as far as the equator, and does not affect the sclera at all. In myopia the chief change is behind the equator, and in the region of the posterior pole of the eye. There is evidence that near work increases myopia, and further, that conditions that cause objects to be held very near to the eye, such as corneal opacities, cataract (it is a common accompaniment of zonular cataract), which reduce the acuity of vision, are also indirect causes.

Types of Myopia.—*Non-Progressive Myopia.*—This type commonly begins about twelve years of age, and by the time the body has reached its full growth, ceases to develop. It rarely reaches a higher degree than about 4 dioptres.

Progressive Myopia.—This type reaches a much higher

degree, and, continuing to increase throughout life, may ultimately reach a figure as high as 30 dioptres.

In the non-progressive type the eyes are perfectly healthy, and may be looked upon as eyes that have developed beyond the usual amount ; in the progressive type pathological changes are always found, which at some period of life will cause disturbances of vision more or less serious.

A word may be said concerning a false form of myopia, due to contraction of the ciliary muscle. It must be borne in mind that the act of accommodation causes an eye to become relatively myopic, so that an individual may be able to see distinctly through a progressively increasing series of concave lenses by an effort of accommodation, and thus give the impression that a degree of myopia exists of which the lens used is the measure ; this power of producing an artificial myopia will show how fallacious may be the estimation by ordinary subjective methods when the accommodation is not paralysed.

The Accommodation in Myopia.—The myopic eye with the accommodation at rest is adjusted for a point between the eye and infinity, its punctum remotum. For example, a myope of 10 dioptres has his punctum remotum at 10 cm. from the eye. If his punctum proximum is at 5 cm. from the eye his range of accommodation is 5 cm.

From the formula deduced on p. 84 his amplitude of accommodation is :

$$a = p - r.$$
$$= 20 - 10 = 10 \text{ D}.$$

The Angle α in Myopia.

In myopia the visual axis usually cuts the cornea to the nasal side of the optic axis of the eye, as is usual also in emmetropia and hypermetropia, but in myopia the angle between the optic and visual axes is smaller since the greater length of the eye decreases the angular distance between the macula lutea and the point on the retina cut by the optic axis.

The sine of the angle MNB is $\frac{\text{MB}}{\text{MN}}$, and, therefore, as the value of MN is increased, so is the value of the fraction decreased,

and therefore, the value of the angle MNB, that is, the angle DNF.

The angle in myopia is 3°, and is usually positive, the optic

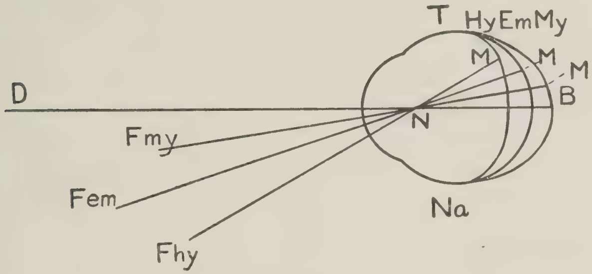


Fig. 87.

axis cutting the cornea to the temporal side of the visual axis, but occasionally the relative positions of the optic and visual axes are reversed, and the visual axis cuts the cornea to the temporal side of the optic axis, producing thereby an appearance of convergent strabismus.

The Relation of Accommodation to Convergence.—In taking as our unit the metre angle for measuring convergence, we shall see that in emmetropia there is a numerical coincidence with the measure of accommodation in dioptres, 1 dioptre of accommodation being accompanied by 1 metre angle of convergence.

This relation does not exist in myopia, and convergence is always in excess of accommodation, as may easily be appreciated by considering an example. In the case of an individual with 4 D of myopia, an object held 25 cm. distant from the eye will be seen without accommodative effort, but the amount of convergence required to prevent diplopia will be 4 metre angles. The importance of this we shall see later in discussing the relation of myopia to divergent strabismus (p. 251).

Visual Disturbances produced by Myopia.—The vision in myopia is always subnormal, and taking normal visual acuity as 6/4·5, the vision will be reduced to 6/6 by so low a degree of myopia as 0·25 D, and an error of more than 2·5 D will reduce the vision to less than 6/60.

The defect is noticed by inability to see distant objects

distinctly, and, in the case of school children, difficulty in reading writing upon the blackboard. On the other hand, there is no difficulty in seeing near objects, provided they are held at or within the punctum remotum—a point in distinguishing myopia from hypermetropia, in which vision is poor for both distant and near objects.

In hypermetropia the defect may be masked, or overcome by an effort of accommodation, but in myopia the eye has no power whatever to overcome the defect, an effort of accommodation rendering the eye more myopic.

In the low degrees of myopia the only complaint will be inability to see distant objects distinctly, but in the higher degrees there will be difficulty in maintaining near vision in comfort. This is largely due to the want of balance between convergence and effort of accommodation, and in extreme cases to the great amount of convergence required to prevent diplopia and the relative immobility of the large myopic eye.

If the myopia is associated with divergent strabismus, or with different degrees of myopia in the two eyes, then accommodation and convergence may be dissociated and vision maintained with one eye only at near ranges, thereby obviating the muscular asthenopia associated with excessive convergence.

In the higher degrees of myopia it is frequently impossible to reach a full acuity of vision, even after the most careful correction of the error of refraction, and in these cases will be found one or other of the various morbid changes that take place in the media or fundus. A frequent complaint is of black specks floating before the eyes, muscæ volitantes, which are often associated with quite healthy eyes, but in myopia the complaints are more commonly met, for not only are opacities in the vitreous more common, and often much larger, but owing to the length of the globe the shadows they cast upon the retina are larger than in emmetropia, what we see being the shadows cast by the opacities floating in the vitreous.

Ophthalmoscopically, changes are frequently seen in the

media and fundus, and these are usually more serious and extensive the higher the degree of myopia.

Treatment of Myopia.—Since the myopic eye is adapted to a finite distance, that is, can only focus an object nearer than infinity, only divergent rays can come to a focus upon the retina. Concave lenses have the power of making parallel rays divergent, and divergent rays more divergent, and so when suitably chosen, may adapt a myopic eye for any distance in space.

In this way we are able to make an eye as physiologically perfect as we can from the optical point of view, and thus hope to diminish the increase which almost always takes place at least during the years of growth, and in some cases throughout life.

We know that the ciliary muscle is able, by its contraction, to hide a condition of hypermetropia in part or whole, and also to exaggerate the amount of myopia present. In this way the amount of myopia which is apparent may represent, not only the static myopia, but also an undetermined amount of artificial myopia produced by the dynamic refraction of the eye. In choosing correcting lenses for myopia, the real myopia must be taken as the standard, and on no account must a lens be prescribed of higher dioptric value than that which corrects the static myopia, hence the rule that the accommodation must be thoroughly paralysed before the correcting lens is sought. This rule applies more especially to children, whose accommodation is particularly active and powerful, and in whom the use of atropine sulphate as drops 1 per cent. in strength, or better still, a solution of the alkaloid of atropia in yellow vaseline of the same strength, three times daily for at least three days, is advised.

When the weakest lens that gives the highest visual acuity has been determined, the patient should be encouraged to use the glasses continuously, as the use of suitable correcting lenses is the best means we have of controlling the increase of the myopia.

Many surgeons order the full correction for constant use in

cases in which there is no presbyopia, and very much may be said in its favour, apart from the fact that it is the logical way in which glasses should be ordered ; certainly the majority of myopic patients are perfectly comfortable, even when their myopia is of high degree. It is the practice of some to order two pairs of glasses when the myopia exceeds a figure in the neighbourhood of 5, one pair with the full correction for distant use, and another of 2 or 3 dioptres less in value for near use. It is, of course, necessary to make an allowance for presbyopia when ordering glasses for reading in myopic patients, as we do in patients who are emmetropic or hypermetropic.

Since accommodation has no effect upon the increase of myopia, as was previously supposed, there is no reason on this score for reducing the power of concave glasses for near use, and bearing in mind the want of balance between convergence and accommodation, relieving the patient of the necessity of accommodation by rendering him artificially presbyopic will make him more uncomfortable by withdrawing the stimulus to convergence brought about by the act of accommodation.

In those rare cases in which a patient with a high degree of myopia has reached adult life without using glasses, considerable difficulty will be experienced with the full correction, more especially for near vision. In these patients an undercorrection is often advisable, not only for near use, but also for distant vision. Glasses are usually worn further from the eye than its anterior principal focus, and the result is to diminish in size the image of objects, so that some patients will see better with lenses that undercorrect their myopia (p. 90). In myopia it is, therefore, necessary that lenses should be worn as near to the eyes as possible, and for this purpose it may be necessary to trim the eyelashes.

In the highest degrees of myopia sufficient convergence to maintain single vision is impossible, not only by reason of the nearness of the punctum remotum, but also of the great size of the eyes, and the disproportion in size between them and the orbit. These patients read with one eye only, usually the eye with better vision, the other eye deviating outwards.

Although the use of the eyes for near work is probably not the cause of myopia, there is no doubt that such a use is the cause of an increase in the amount of myopia once it is established, therefore, especially in the young individuals whose growth is not complete, near work must be restricted.

The determining factor in the increase of myopia is convergence, and bearing this in mind the arguments against reducing the power of reading lenses are much strengthened, as patients with glasses which undercorrect their myopia tend to bring their work nearer to their eye, and so increase their convergence.

Myopic patients must, therefore, always keep near work at a good distance, say 15 inches, they must sit upright, with the illumination, which must be adequate, behind the left shoulder. The importance of illumination is to prevent work being held too near to the eyes, and thus reading by firelight or in bed must be forbidden. There should be periods of rest during work, and in this way the amount of reading that is safe is greater than if the reading is continuous.

All myopic children should be examined at least every twelve months, and, if necessary, refracted under a cycloplegic.

In some places a special school curriculum is arranged for children who suffer from high degrees of myopia, especially when rapidly progressive, in which instruction is carried out mainly by word of mouth, and such near work as is necessary is performed by writing on a blackboard with chalk, using large figures.

Hypermetropia.—Hypermetropia, hyperopia, or "far-sight,"

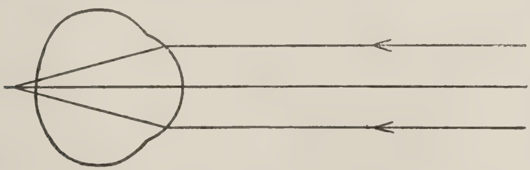


Fig. 88.—Hypermetropia.

is that form of ametropia in which, with the accommodation at rest, incident parallel rays come to a focus behind the retina ;

otherwise considered we may say that in hypermetropia the retina cuts the optic axis of the eye between the dioptric apparatus and its principal focus, so that parallel rays cause a circle of diffusion upon it. We know that the punctum remotum or conjugate focus of the emmetropic eye is at infinity, and that of the myopic eye at less than infinity, and we have seen in considering emmetropia and myopia that for a clear image to be formed upon the retina rays must proceed from the punctum remotum.

In hypermetropia only convergent rays will come to a focus upon the retina, and consequently the punctum remotum is

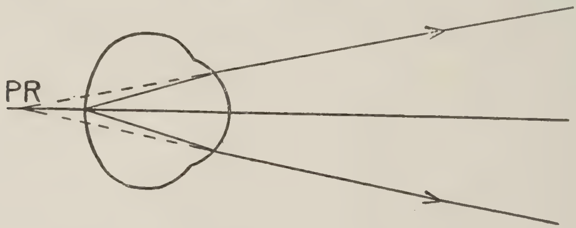


Fig. 89.—Punctum Remotum in Hypermetropia.

beyond infinity, that is, it is a point behind the eye towards which the rays converge. This is a virtual focus, and may be found by continuing the rays backwards until they meet behind the eye as seen in the diagram (Fig. 89).

Now convergent rays, those coming from a point further than infinity, do not exist in nature, and so the hypermetropic eye

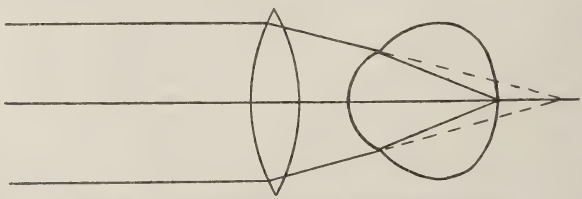


Fig. 90.—Correcting Lens in Hypermetropia.

is unable to form a sharp image of any object held at any distance, that is, the hypermetropic patient is unable to see either distant or near objects clearly.

A convex lens has the property of rendering parallel, or less

convergent rays, more convergent, and so with a suitable convex lens rays may be made to proceed towards the punctum remotum of the hypermetropic eye, and so cause the hypermetropic patient to see clearly.

As a result of the reversibility of rays in optics, rays of light proceeding from a point upon the retina of a hypermetropic eye will leave that eye in a divergent direction as if they proceeded from the punctum remotum of the eye, the conjugate focus of the retina.

There are several ways in which hypermetropia may be caused:

(*a*) There may be an actual shortness of the eye: *axial hypermetropia.*

(*b*) The length of the eye may be normal, but the refractive power of the dioptric mechanism of the eye may be in some manner defective: *refractive hypermetropia.*

Axial Hypermetropia.—A diminution in the length of the eye is the commonest cause of hypermetropia, and in its higher degrees is the constant cause.

Considering axial hypermetropia, the commoner form, as due to a lack of development of the eye, in that the eye is smaller, and its antero-posterior measurement is smaller than that of the emmetropic eye, we may expect to find some difference in appearance between the hypermetropic and emmetropic eye. In the low degrees of hypermetropia little difference can be found, but in the medium degrees very often an inspection of the globe will enable the condition to be diagnosed. The smallness and extensive mobility of the eye is noticeable, and if the eye be strongly rotated to the nose, and the lids drawn outwards, the strong curvature of the equatorial region is appreciated. This is in marked contrast to the myopic eye, in which we have seen there is considerable flattening of the equatorial region. This observation will impress upon the observer the fact that the hypermetropia is due to an alteration in the length of the globe, and not in the refracting surfaces. Furthermore, ophthalmometric examinations have shown that there is no general flattening in the

curvature of the cornea, which is, in some cases, even more curved than that of the emmetropic eye.

In the highest degrees the signs of arrested development are marked, and such conditions as microphthalmos and coloboma of the iris are sometimes seen.

Refractive Hypermetropia.—*Curvature Hypermetropia.*—This may be produced by a flattening of the curvature of the cornea, either congenital or acquired, as the result of disease.

It may also be caused by a deficiency in the acuteness of curvature of one or both surfaces of the lens.

In both the above conditions the radius of curvature of the surfaces is longer than normal.

Index Hypermetropia.—(*a*) The index of refraction of the cornea or aqueous is too low.

(*b*) The total index of refraction of the lens is too low, which may be caused by a low index of the nucleus of the lens, or a high index of the cortex, which, acting as concave menisci, would necessarily lower the refractive power of the lens as a whole.

(*c*) The index of refraction of the vitreous may be too high, thereby reducing the refractive power of the lens.

Absence of the Lens (*Aphakia*).—The crystalline lens has a refractive power equal to that of a + 10·00 D lens placed in front of the eye, and so if the lens is absent from the pupillary area, either by dislocation or operative measures, the eye will become strongly hypermetropic.

The Measure of Hypermetropia.—A diminution in the length of the eye of 1 mm. will cause a hypermetropia of 3 dioptres, and so it happens that the shorter the eye, the higher the degree of hypermetropia. The nearer the retina to the dioptric apparatus of the eye, the more divergent will be the rays leaving the eye from a point on the retina, and, consequently, the more convergent must be the rays to come to a focus upon it, and the nearer must be the punctum remotum to the eye.

In myopia we were able to measure directly the distance of the punctum remotum from the eye, and we saw that this distance measured approximately the focal length of the lens which corrected the myopia. The value of the lens was

expressed in dioptres, and we spoke of the amount of myopia in terms of the dioptric value of the lens which would correct it by causing parallel rays to diverge from the punctum remotum of the eye.

Now, in hypermetropia, owing to the fact that the punctum remotum is behind the eye, it is not possible to measure the distance from the eye directly; we may, however, measure the distance of the punctum remotum indirectly by finding the focal length of the lens which gives the highest acuity of vision with the accommodation at rest.

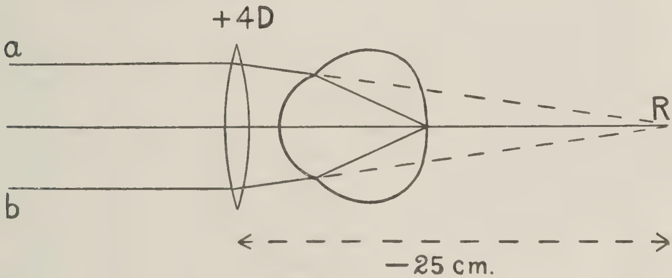


FIG. 91.

Let r = the error of refraction.

R = distance of the punctum remotum measured in centimetres.

Then in the case shown in the diagram:

$$R = -\frac{100}{4} = -25 \text{ cm.}$$

As the punctum remotum is at the principal focus of the lens correcting the ametropia, as shown in Fig. 91, it will be behind the eye at 25 cm. from the situation of the correcting lens placed at the anterior principal focus of the eye. Theoretically the distance of the punctum remotum from the eye should be measured from the cornea; as, however, the correcting lens is at least 13 mm. in front of the cornea, its focal length overestimates the distance of the punctum remotum behind the eye by this amount and it therefore underestimates the actual amount of hypermetropia.

Clinically we make our measurements from the anterior principal focus of the eye, and when we speak of the punctum remotum being so many centimetres from the eye, we mean that the measurement has been taken from the anterior principal focus. If we did not place the correcting lens at, and take our measurements from, this point, we would obtain discordant results, as may be seen by this example.

Take a hypermetropic eye whose punctum remotum is 111 mm. behind the cornea. A + 9·00 D lens in this situation would correct the ametropia, since the focal length of such a lens is 111 mm. If, however, we take our measurement from the anterior principal focus of the eye, the distance of the punctum remotum will be 126 mm., that is, the focal length of a + 8·00 D, and so on, for any point chosen in front of the eye. It will be noticed that the farther the correcting lens is removed from the eye, the less is its dioptric value. This is obviously due to the fact that its principal focus must always coincide with the punctum remotum of the eye.

Varieties of Hypermetropia.—It has been shown above that hypermetropia may be measured, and also corrected by increasing the dioptric power of the eye by the addition of a suitable convex glass ; by this means a sharp image may be formed upon the retina. We may, in fact, consider that a hypermetropic eye is one whose dioptric apparatus is deficient in refractive power in relation to the situation of the retina, and that its dioptric value requires strengthening.

We are able to increase the dioptric value of the eye by using our accommodation, as we have already seen. The hypermetrope makes use of this power, and, indeed, if he did not do so he would be in the unfortunate position of never seeing distinctly any object, at whatever distance.

The myope has the compensation of being able to see objects at his punctum remotum distinctly, although he is unable to see far distant objects in detail. The emmetrope makes use of his accommodation when viewing objects at a distance nearer than infinity, more especially objects within a few feet of his face. The hypermetrope uses his accommodation when viewing

distant objects, and the amount of hypermetropia that he is able to correct thereby depends upon his power of accommodation, whilst his ability to see distant objects distinctly depends not only upon his power of accommodation, but also upon the amount of hypermetropia.

This relationship has given rise to several varieties of hypermetropia, which from the clinical point of view are most important.

Manifest Hypermetropia (Hm).—It is very usual for the whole of the hypermetropia to be concealed by an effort of accommodation, especially when the error is of low degree, and the accommodation powerful, as in children. In many cases, especially in young persons, in spite of this power to mask hypermetropia, the addition of a convex lens to the eye up to a certain power is accepted, and the same visual acuity, which was at its greatest without a glass, is still retained.

If a convex lens be placed before an emmetropic eye, maximum visual acuity will no longer be maintained, and we have shown that in the case of hypermetropia the accommodation may be relaxed, and the convex lens take the place of the refractive power previously added to the crystalline lens by the contraction of the ciliary muscle.

The strongest convex glass with which an eye retains its maximum visual acuity is the measure of the *manifest hypermetropia* (Hm).

Total Hypermetropia (Ht).—If the hypermetrope be young, it is unlikely that the use of convex glasses will cause him to relax his accommodation entirely, so that the manifest hypermetropia is not a measure of the total hypermetropia. This is measured by the strongest convex lens with which an eye retains maximum visual acuity after the accommodation has been paralysed by some drug such as atropine.

Latent Hypermetropia (Hl).—This is the difference between the total and manifest hypermetropia.

$$\text{Hl} = \text{Ht} - \text{Hm}.$$

As age advances and the power of accommodation is gradually lost, so does the manifest hypermetropia increase, and the latent

diminish, until the whole of the hypermetropia has become manifest. In the higher degrees of hypermetropia more tends to become manifest and less latent, whereas in the lower degrees more tends to be latent.

Facultative Hypermetropia (Hf).—When speaking of manifest hypermetropia, we spoke of the strongest convex lens with which maximum visual acuity could be obtained as its measure.

It is not necessary that the individual who has a certain measure of manifest hypermetropia should have maximum visual acuity without the convex lens, on the other hand he may. In both cases there is a certain measure of hypermetropia that has been masked by the accommodation, and this is termed the *facultative* hypermetropia.

In one case all the manifest hypermetropia is facultative, whereas in the case that has not maximum visual acuity without a convex lens, only a portion of the manifest hypermetropia is facultative.

Absolute Hypermetropia (Ha).—This is the hypermetropia that cannot be overcome by an effort of accommodation and $Ha = Ht - Hf$. In high degrees of hypermetropia some is usually absolute, and as age advances and the power of accommodation becomes gradually less, so does more and more hypermetropia become absolute, so that even in low degrees facultative hypermetropia of youth becomes absolute hypermetropia of later years. In old age all hypermetropia becomes absolute.

The following example will show how the varieties of hypermetropia stand one to the other.

An eye reads 6/18, and with a + 1·50 D, reads 6/6, but can still read 6/6 quite plainly with a + 3·50 D.

If atropine be now applied it is found that 6/6 is still read with + 4·50 D.

Tabulating the results :

$$V = 6/18 \quad \bar{c} + 1{\cdot}50\text{ D} = 6/6.$$
$$\bar{c} + 3{\cdot}50\text{ D} = 6/6.$$

After atropine :

$$\bar{c} + 4{\cdot}50\text{ D} = 6/6.$$

The total hypermetropia .	. .	= 4·5 D
Manifest hypermetropia	. .	= 3·5 D
Facultative hypermetropia	.	= 3·0 D
Latent hypermetropia	. .	= 1·0 D
Absolute hypermetropia	. .	= 1·5 D

The usual refraction of the eye at birth is one of hypermetropia, so that we may consider axial hypermetropia as arising from a lack of growth of the eye, but there is a type of hypermetropia that arises in later life that we may call *acquired* hypermetropia, in contradistinction to the congenital form.

At the age of fifty-five years a previously emmetropic eye will have developed 0·25 D of hypermetropia, which gradually increases in amount until at eighty years of age 2·50 D of hypermetropia will be found.

We have seen that the lens may be considered as a highly convex nuclear portion of high refractive index, combined with two minus menisci. As age advances, and the lens becomes more and more sclerosed, so does the index of refraction of the menisci increase. Their dioptric value, therefore, increases, and they cause a diminution in the power of the lens as a whole, so that parallel rays that were brought to a focus upon the retina in earlier years come to a focus farther back as age advances.

The Accommodation in Hypermetropia.—The hypermetropic eye with the accommodation at rest is adjusted for a virtual punctum remotum. For example, a hypermetrope of 4 dioptres has his punctum remotum 25 cm. behind the eye, *i.e.*, at $-$ 25 cm., or $-\frac{1}{4}$ metre from his eye. At the age of twenty his punctum proximum will be found 16 cm. or $\frac{1}{6}$ metre from the eye. His range of accommodation, therefore, is infinite, and his amplitude of accommodation, using the formula, is :

$$a = p - r.$$
$$= 6 - (-4) = 10 \text{ D}.$$

The diagram, Fig. 92A, shows that the eye must exert 4 dioptres of accommodation in accommodating from the punctum remotum to infinity, and a further 6 dioptres in

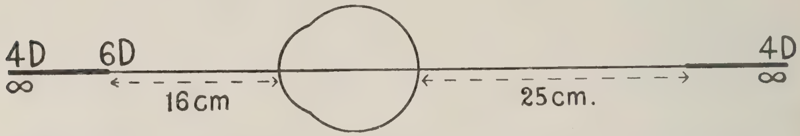


Fig. 92A.—Diagram of the Amplitude of Accommodation in an adult of twenty years with 4 D of Hypermetropia.

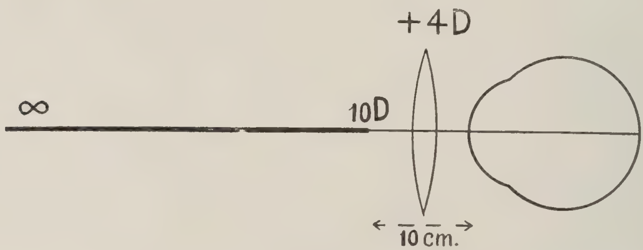


Fig. 92B.—Diagram of the Amplitude of Accommodation of the same Hypermetrope wearing a correcting lens.

accommodating to the punctum proximum at 16 cm. If, now, the hypermetropia be corrected with a suitable lens of + 4 D, then the eye has available all its accommodation for focussing from infinity to a near point at 10 cm. from the eye (Fig. 92B).

The Angle α in Hypermetropia.—The visual axis cuts the cornea to the inside of its optic axis in hypermetropia. This is usual in emmetropia, but in hypermetropia the angle between the visual and optic axis is larger, since the shortness of the eyeball increases the angular distance between the macula lutea and the point on the retina cut by the optic axis.

The sine of the angle MNB is $\frac{MB}{MN}$, consequently, if MN is decreased in length so does the value of the fraction increase,

and, consequently, the value of the angle MNB, that is, the angle DNF.

In emmetropia the angle α is 5°, and in hypermetropia it may be so high as 8°, and, owing to the fact that the visual axis

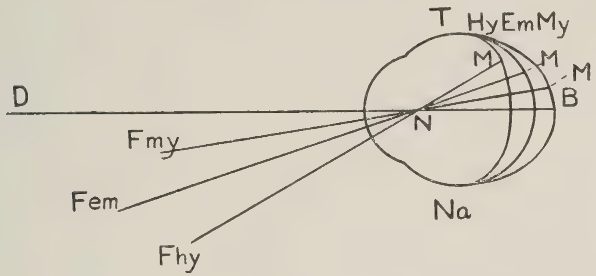


FIG. 93.

cuts the cornea to the nasal side of the optic axis, we say that the angle α is positive. This gives the appearance of a divergent strabismus in cases where the angle is large.

The Relation of Accommodation to Convergence.—We have seen in discussing the relation of accommodation to convergence in myopia, that in myopia convergence is always in excess of accommodation. In hypermetropia there is an exact converse, and accommodation is always in excess of convergence. In the case of an individual with 4 D of hypermetropia, an object held at 25 cm. distant from the eye will be seen with 8 D of accommodation, whereas the amount of convergence required is 4 metre angles. The eye is therefore focussed for one distance and converged for another. This is a fruitful source of discomfort, and also, as we shall see later, may result in a permanent disturbance in the muscular balance of the eyes, producing convergent strabismus.

Visual Disturbances produced by Hypermetropia.—All the symptoms of hypermetropia may be traced to the effort of accommodation imposed upon the eye by the defect in its focussing power.

The hypermetrope not only uses more accommodation when looking at near objects than the emmetrope, but he finds it

necessary to use his accommodation continuously so as to obtain a sharp image of a distant object, whereas the emmetropic eye is focussed for distant objects when its accommodation is completely relaxed.

It will be appreciated from what has been said above, that the capacity of the hypermetropic eye to maintain acute vision for both distant and near objects depends upon the relation of the hypermetropia to the amplitude of accommodation, and, consequently, in a particular case, the distant and near vision may be quite good, whereas in another the distant vision may be good and the near vision defective, and in a third, both distant and near vision imperfect. If the degree of hypermetropia is very high indeed, the individual may give up all attempt at distinct vision for near objects by an effort of accommodation, and hold the object very near to his eye, so as to make up for indistinctness of vision by an enlargement of the retinal image. In the lower degrees, distant vision being good, the difficulty in near vision is overcome by the individual holding his book further from his eye than is usual, and so calling upon a less effort of accommodation. In this way the hypermetrope of low degree continues with near work, but sooner or later even he is inconvenienced by a series of symptoms collected together under the name of *accommodative asthenopia.*

When using the eyes for near work the vision becomes dim, but it is found that by closing the eyes for a few moments the vision has improved upon opening the eyes again owing to the short rest given to the ciliary muscle. There is a sensation of heaviness and pressure upon the eyes, often pain in the eyes themselves, and pain in the frontal region more or less severe. With children, who are not so observant of defect of vision, frequently the outstanding complaint is headache, and if they are asked the situation of the pain, they place the hand across the frontal region above each supraorbital ridge, and upon enquiry, the relation of the headache to near work is often admitted. True migraine attacks may occur, which are relieved considerably when the correcting lenses are worn. Although

there is frequently a direct connection between the degree of hypermetropia and the severity of the symptoms, a high degree of hypermetropia causing marked asthenopia and *vice versâ*, nevertheless, considerable distress may occur even when the hypermetropia is small in degree, and the amplitude of accommodation good. Such accommodative asthenopia occurs after an illness, even in young people, and is not infrequently seen in mothers during the period of lactation.

Again, asthenopia with a low degree of hypermetropia is often seen in those young people whose work makes considerable call upon the accommodation.

The relation of hypermetropia to convergent concomitant strabismus will be discussed in another chapter.

Anatomically the hypermetropic eye is shorter than the emmetropic eye, but these changes extend also to the parts of the eye in front of the equator. The acuteness of the curve of the sclera has already been mentioned, and in such eyes the cornea is smaller than normal, and the anterior chamber shallower, conditions which have an important bearing upon the incidence of glaucoma.

Ophthalmoscopically certain peculiarities are more common in hypermetropia: tortuosity of the retinal vessels, due possibly to the comparatively confined space of the retina in the small eye, pseudo-optic neuritis and inferior crescent (often associated with a lowered visual acuity), and a high reflex from the retina, the so-called " watered silk " appearance.

Treatment of Hypermetropia.—This consists in prescribing suitable spectacles with convex lenses, and thereby increasing the total refractive power of the eye. A little judgment is required in the prescribing of glasses in hypermetropia, since if insufficiently strong glasses are ordered, then the symptoms are not relieved although the distant and near vision may be quite good, whereas if glasses too strong are ordered the patient complains of mistiness in his distant vision.

If in the presence of hypermetropia visual acuity is good, and there are no symptoms of asthenopia, then certainly glasses should not be prescribed, and no ill effect will result from the

patient going about without spectacles. In children the total hypermetropia should be estimated by retinoscopy, with the accommodation completely paralysed by the use of atropine. This should be confirmed by a subjective examination, and, provided the child can read letters fluently, it should never be omitted. Great assistance will be obtained especially in confirming the axis of the estimated cylinder in cases of astigmatism.

Very little assistance may be expected by examining the child when the effect of the atropine has passed away, so that we find by experience that the lens which corrects the total hypermetropia under atropine may be ordered, *less* 1 dioptre, which is the measure of the tone of the ciliary muscle. For example, if a child under the influence of atropine has full visual acuity with + 4·50 D, then the glass ordered for use will be + 3·50 D.

In cases of squint such a plan should always be followed, and instructions given for the constant use of the glasses; whereas if the distant vision be good in a case of asthenopia with near use of the eyes, then the glasses need only be used for near work. It is a good plan in all children to arrange for the use of the glasses in the first instance, before the effect of the atropine has passed away.

In young adults, if the hypermetropia be high it is often not wise to give the full correction at once. Owing to an excessive use of the ciliary muscle it has become hypertrophied, and it will not easily relax completely. It is usual in these cases to order the lens that corrects the manifest hypermetropia *plus* one-quarter of the latent hypermetropia. If the patient has been in the habit of using glasses then we are able subsequently to order the lens that corrects the total hypermetropia. An allowance of 0·75 D must be made for the recovery of tone in the ciliary muscle when the correction has been made under homatropine, and an extra 0·25 D deducted for the accommodation necessary for reading the test types at 6 metres distance.

In older patients, whose accommodation is less powerful, more and more of the total hypermetropia becomes manifest

as age advances. In such cases we order the glass that corrects the manifest hypermetropia for distant use if necessary, together with the presbyopic correction for near vision.

Astigmatism.—The types of ametropia that we have so far considered have been spherical errors, and capable of correction by spherical lenses; we have also seen that in most instances they have depended upon an alteration in the position of the retina, the refractive power of the dioptric media remaining constant.

It was pointed out that these errors could be produced by some alteration in the curvature of the refracting surfaces, although probably such a cause was rare. There is, however, one common error of refraction depending upon an alteration in the curve of the refracting surfaces, which we must now consider.

We have hitherto considered that the different refracting surfaces of the eye, the cornea and lens, are spherical, so that planes passing in the axis of the eye in all meridians will show, where they cut these surfaces, a similar curve. Further, these surfaces, or at any rate, those portions used for direct vision, are centred upon the same axis, and so rays refracted by these surfaces are homocentric, and will converge to or appear to diverge from a common point.

It is rarely that these conditions are exactly satisfied, and careful laboratory research will show that there is a slight difference in curvature in different meridians, the result being that all the rays refracted by these surfaces do not focus towards a common point. With these very slight errors we are not concerned, as they do not affect direct vision or produce symptoms, and, consequently, are not considered as errors from the point of view of clinical ophthalmology.

Substantial errors of curvature are the ones with which we have to deal in practice, and these are designated astigmatism (ἀ, privative; *στίγμα*, a point).

Regular Astigmatism.—Astigmatism may affect the surfaces of either cornea or lens, and in the case of the lens it may be due, not only to a difference of curvature in various meridians,

but also to a tilting of the lens on the optic axis, the refractive system then being no longer homecentric.

The main seat of astigmatism is in the cornea, and when present, measurements will show different radii of curvature in different meridians. In regular astigmatism, which is a congenital defect in construction, the directions of the greatest and least curvature of the cornea are at right angles one to the other, and it is, consequently, the only form of astigmatism which may be satisfactorily corrected by lenses. The curvatures are usually such that the meridian of greatest curvature lies in the vertical plane, and that of least curvature in the horizontal, the curves resembling those of a chicken's egg placed upon a table. Such astigmatism is called "with the rule," the other condition being "against the rule." Although most commonly the axes of astigmatism lie in the vertical and horizontal meridians, they may lie in any other of these meridians, in which case the astigmatism is called oblique.

The cornea may, or may not, be the only surface at fault, and the corneal astigmatism may be increased or more or less corrected by astigmatism of the lens, and so an instrument such as the ophthalmometer, which measures only the corneal astigmatism, may give quite a wrong impression of the total astigmatism, although it often gives helpful information as to the axes in which the meridians lie; therefore only those methods which measure the total astigmatism are perfectly reliable.

If we have a spherical lens on which falls a beam of light parallel to its principal axis, these rays will be concentrated at the principal focus of the lens. If now the lens be tilted so that the bundle of rays is no longer parallel to the axis, the system ceases to be homocentric, and the rays will now be refracted as by an astigmatic surface. This point is important in practical ophthalmology, in showing that lenses, ordered for the correction of errors of refraction, must be worn in such a way that rays do not traverse them obliquely. This is not easily attained, as the head and spectacles remain fixed whilst the eyes are constantly moving; in the lower degrees of

ametropia the point is not of very great importance, but in the higher degrees, as seen in extreme myopia, and in the use of high-powered lenses after cataract extraction, considerable diminution of vision will result. It is noticeable that the patients who wear such lenses rapidly develop the habit of moving the head, and, consequently, the glasses and eyes, in this manner retaining their relative position.

Refraction by an Astigmatic Surface.—Let us take an astigmatic refracting surface arranged so that the principal meridians lie as in the cornea, the vertical meridian BB′ having a greater curvature than the horizontal AA′. The rays in the meridian BB′ will travel towards the point *f*, the principal focus, and the rays in the meridian AA′ will travel towards F, the principal focus, so that such a system has two principal foci and two focal lengths, which correspond to the two principal meridians. The rays in these meridians are homocentric, and all along these meridians a plane tangential to the surface is perpendicular to the plane of the meridian, whereas elsewhere a plane tangential to the surface is no longer at right angles to the plane of the meridian. The result is that all the incident rays contained in other meridians than the principal meridians, will not meet on the principal axis, but will be separated from it by an amount varying with the point of incidence. All these rays, therefore, meet in *focal lines*, which are shown in the diagram at CC′ and *cc″*, crossing the axis vertically at F and horizontally at *f* respectively.

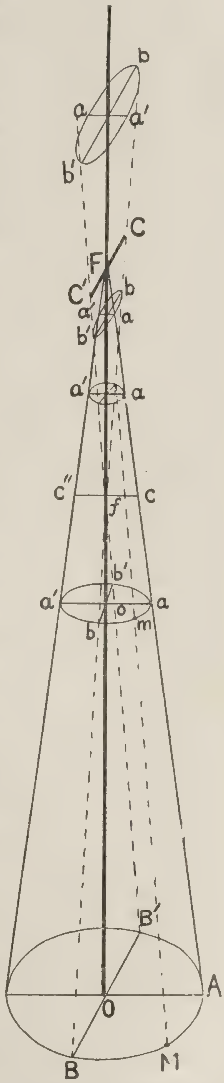


Fig. 94. (Imbert.)

Thus rays emanating from a point give rise to a cone, which, after refraction, gives, not two foci, but *two focal lines* of Sturm, and the beam of light thus refracted is called the *conoid of Sturm*, the interval between the two focal lines being termed the *interval of Sturm*, which is the measure of the astigmatism.

It will be noted that in the eye the position of the retina in no way affects the amount of astigmatism, as the interval fF remains constant, and if the position of the retina alters during the period of development, what may originally have been a hypermetropic astigmatism will be changed into a mixed or it may be a myopic astigmatism, but the amount of astigmatism remains unaltered.

If a screen be placed at varying distances from such a refracting surface it will be seen that the image obtained will vary from an almost circular patch near the refracting surface, then ellipsoidal, until the first focal line is reached, then through an ellipse to a circular patch. After this, the patch becomes ellipsoidal, with the major axis at right angles to that of the ellipse nearer to the surface, until the second focal line is reached which is at right angles to the first focal line.

The result of astigmatism is that the eye is unable to form a sharp picture upon the retina, which cannot be at the focal point of the two meridians of the cornea at the same moment, so that when the object is at the conjugate of the retina in one meridian, the conjugate of the other meridian must lie either in front of or behind the retina.

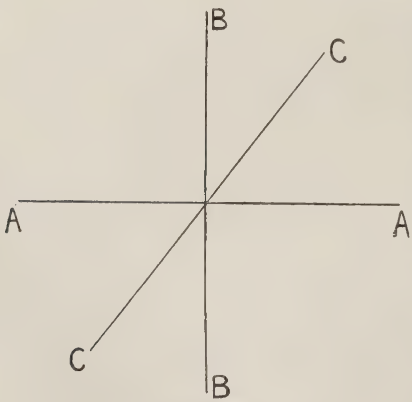


Fig. 95.

Let us take two lines crossing each other at right-angles, and placed before an eye that is astigmatic, with the meridians precisely vertical and horizontal. If the eye is focussed for rays of light in its horizontal meridian,

then the vertical line will be clearly seen. This will be clear from the following considerations.

A line may be considered as a collection of numerous points, in the case of the line BB placed in a vertical series ; these points fuse with one another, and so will produce a vertical line in focus with a slight extension of the ends of the line, which will, therefore, appear a little longer. The thickness of the line will be exactly seen and there will only be a little distortion at the ends in the length of the line.

Again, imagine an astigmatic cornea cut with a great number of horizontal sections, and a vertical line placed behind such a cornea so that it lies in the focal plane of the horizontal meridian. If a single section be taken, then the thickness of the line will be clearly seen. As the cornea is reconstructed so does the line grow in length, the imperfectly focussed upper and lower end of each section overlapping each succeeding section, until the end of the line is reached, the image of which will appear indistinct and blurred, owing to circles of diffusion and, therefore, slightly lengthened.

The line AA in the horizontal plane will, therefore, appear blurred in its thickness, and as the ends are well focussed, they will appear comparatively sharp, and not frayed out as will the ends of the vertical line.

With a series of oblique lines placed in intermediate positions such as CC, as the lines approach the vertical they will appear well defined, and as they approach the horizontal, less well defined ; in this particular case the maximum sharpness is seen in the vertical line, the minimum in the horizontal.

Clinical Varieties of Regular Astigmatism.—We have already seen that the curvature of the cornea, the common site of astigmatism, is usually greatest in the vertical meridian, and less in the horizontal, and that more commonly the meridians are exactly vertical and horizontal. Such astigmatism is called, *with the rule*, and when reversed, *against the rule*. When the meridians are otherwise placed, the term oblique astigmatism is applied.

Simple Astigmatism.—When the conjugate of one of the focal

lines of Sturm lies upon the retina, the condition is known as simple astigmatism. If the conjugate of the other focal line lies behind the retina, the condition is called simple hypermetropic astigmatism, and if in front of the retina, simple myopic astigmatism.

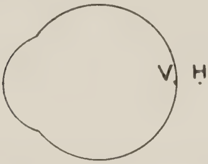


Fig. 96.—Simple Hypermetropic Astigmatism with the Rule.

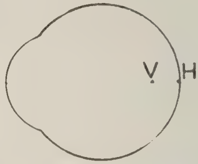


Fig. 97.—Simple Myopic Astigmatism with the Rule.

Compound Astigmatism.—In simple astigmatism, the eye in one meridian is emmetropic. In compound hypermetropic astigmatism each meridian is hypermetropic, one more hyper-

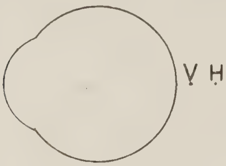


Fig. 98.—Compound Hypermetropic Astigmatism with the Rule

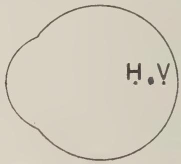


Fig. 99.—Compound Myopic Astigmatism with the Rule.

metropic than the other; and in compound myopic astigmatism each meridian is myopic.

Mixed Astigmatism.—In this case one conjugate is in front of the retina, the other behind.

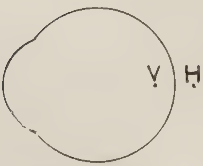


Fig. 100. — Mixed Astigmatism with the Rule.

The Measure of Astigmatism.—The measure of spherical ametropia is theoretically the dioptric value of the correcting spherical lens placed at the principal point of the eye, and in practice the spherical lens placed at the anterior principal focus. The difference between the dioptric values of the lenses that correct the two principal meridians is the measure of the astigmatism.

Thus, in a case of compound hypermetropic astigmatism, if the correcting lenses are + 2 D sph in the vertical meridian,

and + 4 D sph in the horizontal, the astigmatism is, therefore, 2 D; and in a case of mixed astigmatism with the horizontal meridian corrected with a + 2 D sph, and the vertical by a − 1 D sph, the astigmatism is 3 D.

Visual Disturbances produced by Astigmatism.—In all forms of astigmatism the visual acuity is reduced, and if the astigmatism is also associated with a spherical error of refraction, the reduction is greater.

Referring to what has been said when dealing with hypermetropia and myopia, it will be appreciated that the reduction is greater when myopia coexists with the astigmatism, than hypermetropia.

When testing with distant test types certain letters are confusing, especially those whose lines of formation run in various meridians, such as Z, X, M, N, and so on.

If a diagram formed of heavy radiating lines be placed before the eye at a distance of 6 metres, and the eye be free of astigmatism, all the rays will appear of equal distinctness and equal intensity of blackness; if, however, astigmatism is present, then the lines in one meridian will be seen more clearly than those in the opposite meridian, the lines fading gradually in distinctness as they pass from the meridian of most distinct vision, reaching least distinct definition in the meridian at right angles to that of most distinct definition.

Suppose the horizontal line be that most distinctly seen, this means that the meridian of least ametropia is vertical, and, consequently, that of highest ametropia will be horizontal, the most distinct line running in the meridian of greatest ametropia. In such a case if the vertical meridian were emmetropic, then probably the horizontal will be hypermetropic, as this meridian, in astigmatism with the rule, is that of least curvature.

The Estimation of the Degree of Astigmatism.—Astigmatism will be suspected in a case in which mistakes are made in reading the letters in a line which may be spoken of as confusion letters, whereas those in the line which are not so confusing are recognised without mistake.

The use of the radiating lines mentioned above will not only

confirm this suspicion, but may give a hint as to the direction of the meridians of greatest and least refraction.

The most accurate method of estimating the amount of astigmatism is by the method of retinoscopy, as will be explained in the section dealing with that subject. The direct method of using the ophthalmoscope will also be of use if the astigmatism be of any marked degree, and retinal vessels running in a horizontal direction will appear sharply focussed if the vertical meridian be emmetropic, whilst those vessels which run in the vertical meridian will be least distinct if the horizontal meridian be ametropic.

As the refracting surface most at fault is the cornea, special methods of examination have been introduced with a view, not only to diagnosing the presence of astigmatism, but also to measuring the amount clinically.

In a very high degree of astigmatism, such as we see in conical cornea, differences in the behaviour of the cornea as a convex mirror as compared with the perfectly spherical cornea, will easily be recognised, and the image in a conical cornea will appear obviously distorted. If the astigmatism be of less degree, then special methods must be adopted to make this distortion apparent, and the most useful will be one in which a pattern is frequently repeated on the surface of an object so that we may compare the image formed in one part of the cornea with that formed in another part at the same time. Such an instrument, known as Placido's disc, has been in use for many years.

Fig. 101.—Placido's disc.

This consists of a series of concentric circles, alternately black and white. If such an object be held in front of a perfectly spherical reflecting surface, the images of these circles will remain the same whatever part of the reflecting surface is used; if, however, the surface be markedly astigmatic, then there will be distortion, which will differ, depending upon whether a portion of the surface used is more or less curved in one direction than another.

The Ophthalmometer.—A more precise method is that of the use of the ophthalmometer. The principle of this instrument has already been explained, so that all that need be done now is to show how this instrument has been applied to clinical use, since, obviously, as used for measuring the curvature of the refracting surface of the eye, it would have no useful application outside the laboratory.

In the original Helmholtz instrument we have a large object whose image in the cornea to be measured is at least one-quarter the diameter of the cornea—it is necessary that this image be of comparatively large size, so that it may be conveniently observed and measured. This object remains constant in size, and the doubling apparatus is variable at will, so that the edges of the two images may be brought into apposition. In the modern ophthalmometer of clinical practice we have a constant doubling of the image, but the object is varied in size; this is merely for convenience of practice, the principle remaining the same.

If we use as a test object a Roman cross whose arms are of equal length, and an image of this cross is formed in an astigmatic cornea so that the limbs of the cross correspond with the principal meridians of the cornea, then the image of the arm in the meridian of greatest curvature will be less in size than that of the arm in the meridian of least curvature, and if we can measure the size of the image, knowing the size of the object, and its distance from the eye, we can calculate the refractive power of the cornea in these two meridians, the difference between which will be the measure of the astigmatism. In place of a cross we use a single linear object, the

image of which in one meridian is measured, and then the object is turned about a central point so as to be at right angles to its original position, and the size of the image in that meridian of the cornea is measured.

The instrument consists of a short-distance telescope, with a prism of doubly refracting Iceland spar between the objectives; the cornea and the images upon it are, therefore, doubled. The object consists of two white plates and the distance they are separated one from the other, the plates being as it were the ends of a linear object, the part between the two ends being invisible. These two plates, or mires, are placed upon an arc attached to the telescope, the concavity of which faces the patient. The image of the object in the cornea is double, and the extremities of the images overlap.

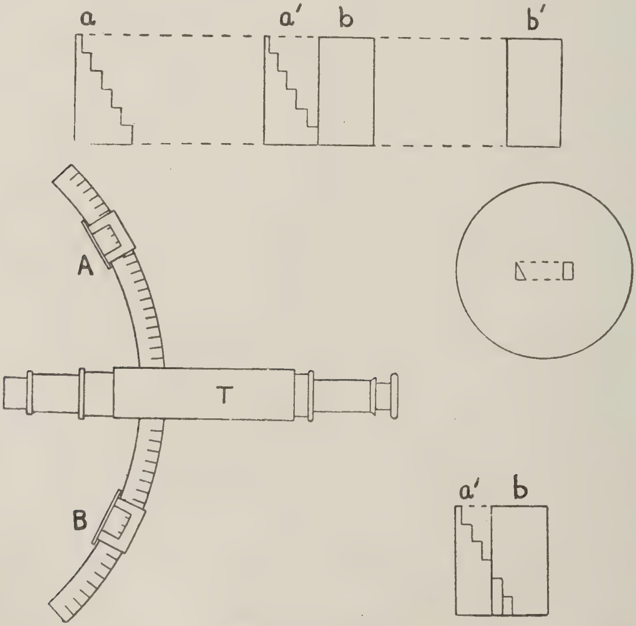


Fig. 102. (Fuchs.)

In the above figure *ab* represents one image, and *a′b′* the other, of AB the object. If we make the object AB smaller by

approximating A to B, then a will approach b, and a' will approach b'. This may be done until the edges of a' and b touch each other, and when this happens, the size of the object AB may be measured by reading the divisions on the arc.

Instead of leaving the observer to work out the radius of curvature of the cornea in this meridian, the arc is so graduated that from the position of A and B the radius of curvature of the cornea and its refractive power in dioptres can be read off.

If, now, the arc be turned through 90°, a similar observation may be made in that meridian, and so the refractive power of the two principal meridians observed, the difference between the two being the measure of the astigmatism.

If the refraction be the same in the two meridians, then the size of the image will be the same, and in the first and second positions of the arc the images of the mires will have the same relative position. If, however, the second meridian has a greater curvature the sizes of ab and $a'b'$ will be less, and a' and b will overlap. The size of the two images may be deduced from the amount of overlap, and the plates are so made as to make this readily observed.

The plate A has a series of steps of such a size that the image of the rectangular plate B will overlap one step of the image a' (the image of A) for each dioptre of difference between the two meridians.

It must be noted that the reading given by the ophthalmometer is that of the difference in refractive power between the two principal meridians of the cornea only, it is not a measure of the total astigmatism of the eye : the measure is of the lens that must be worn at the principal point of the eye, and, consequently, in contact with the cornea, whereas glasses are worn at the anterior principal focus of the eye, about 15 mm. in advance of the cornea. The ophthalmometer does not give the measure of the total refraction of the eye, and the measure of hypermetropia or myopia must be made by other means.

The Use of the Astigmatic Fan.—This may be a very valuable aid in cases in which a mydriatic is not used, and the pupil is too small for an accurate estimation of the refraction by

retinoscopy. It is especially useful in deciding the presence or absence of low degrees of astigmatism, and the axis in which the correcting cylinder should be placed.

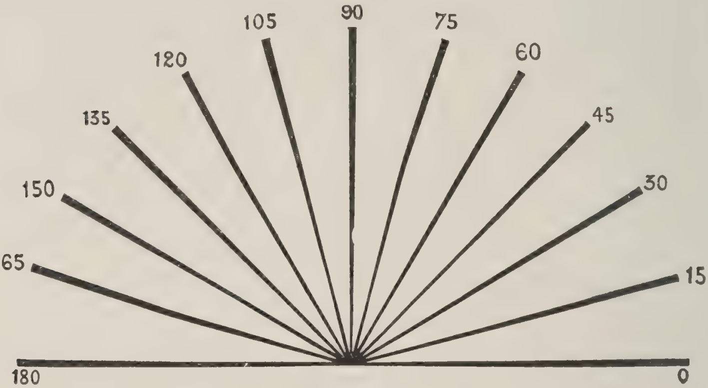


Fig. 103.

The patient's gaze is directed to the fan of radiating lines at 6 metres distance, whose direction varies from 0° to 180°, and one eye is examined at a time. It is found that better results are obtained by "fogging" the vision, that is, reducing the distant vision to 6/18 by a convex or concave glass. When this has been done, a patient with astigmatism will just be able to distinguish one set of lines clearly, the remaining lines being indistinct, more especially those at right angles to the most distinct line. The distinct line gives the meridian of *greatest* curvature, and then by placing concave cylinders in the trial frame, with their plane axis at right angles to this line, we are able to choose a suitable cylinder to render the lines clear that were previously indistinct.

Suppose, for instance, the line at 90° is the most distinct, the line at 180° will be least distinct, then by placing concave cylinders with their axes at 180°, the lines at 180° will be made as distinct as those at 90°. If we now direct the patient's gaze to the test types we are able by modifying the sphere to find the lens combination that gives acutest vision.

No method of estimation can replace retinoscopy on account

of its great accuracy, and the independent position in which it places the surgeon, and it must be remembered that, owing to defects in centering of the refractive media of the eye or the oblique position of the lens, the patient is able to detect errors by subjective tests that we are unable to correct with lenses.

Irregular Astigmatism.—This is usually due to disease of the cornea, more especially to the local alteration of the curvature of the cornea due to cicatrisation after ulceration, in which vision is also reduced by the opacities in the cornea. A very marked degree of irregular astigmatism is seen in conical cornea in which the vision is also reduced by a high degree of negative aberration, and often by a scar near the apex of the cone.

Such astigmatism cannot wholly be corrected by lenses, and the ophthalmometer or astigmatic fan will give little or no help. Sometimes a great deal of help can be obtained by retinoscopy, but usually it is by a method of patient experiment that any help to the patient can be given.

The best plan is to make use of the stenopæic slit, which consists of a diaphragm of metal or vulcanite in the middle of which is a slit 2 mm. in width.

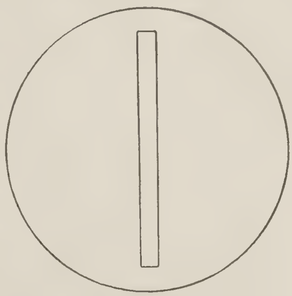


FIG. 104.

This is placed before the eye so that the slit is exactly opposite the pupil, and is then turned in various meridians until the best vision is obtained. With the slit in this position a note is made of the best vision obtained with the highest convex or lowest concave glass. We then repeat the observation with the slit at right angles to its previous direction. It is well, also, to repeat the experiment in intermediate meridians.

For example, with the slit placed horizontally the best vision is obtained with a + 2 D sph, and with the slit vertically placed with a − 3 D sph, the glass suggested will be a + 2·00 D sph with a − 5 D cyl ax. 180°. This, at any rate, will be useful information on which to work, but only patient trial will lead to the glass which gives the best vision.

Anisometropia.—This is the condition in which there is a marked difference in the refraction of the two eyes. Theoretically, anisometropia is present when the difference in refraction between the two eyes is ever so slight, and even small degrees may cause symptoms of asthenopia.

Practically, the eyes cannot be accommodated to different extents at the same time, the difference possible amounting to but 0·12 D.

When the eyes, with a similar static refraction, are accommodated for an object held midway between the two eyes, no difference of accommodation is necessary in the two eyes to produce equally sharp images upon the retinæ, but, when the object is held to one side, at a near range, an equal amount of accommodation in each eye will not produce equally sharp images in the two eyes.

In a similar way, if the two eyes have a different static refraction, an object held in the mid line between the eyes will not produce sharp images in each eye when equal degrees of accommodation are exerted in the two eyes.

In the condition of anisometropia we can easily prove that unequal degrees of accommodation are not exerted by the two eyes. If we take a single line of small print, and place before one eye a weak prism, base downwards or upwards, then the line will be reduplicated, one just above the other : it will be found that the two lines are never equally sharply focussed, one will always be more or less blurred. The same will be found when the line of print is held well to one side at a close range, in similar circumstances, before an individual with the same static refraction in each eye.

In anisometropia the eye that is properly focussed is that which requires the less accommodative effort for the distance at which the object is held, so that when one eye is myopic and the other emmetropic, the myopic eye is correctly focussed, and when one eye is hypermetropic and the other emmetropic, the emmetropic eye is properly focussed.

When the object is held at close range to one side of a pair of eyes with equal static refraction, and of equal visual acuity,

it is the eye that lies nearer the object that decides the amount of accommodation used.

Up to 2 D, correcting glasses can usually be worn after a short trial, but above this, greater and greater difficulty is experienced as the amount of difference increases, and 4 D is certainly the limit. There are various reasons why this difficulty should occur. If we were able to wear glasses exactly at the anterior focus of the eye the difference in size of the retinal images would not be different in the two eyes ; but we always have our spectacle glasses in advance of the anterior focus of the eye owing to the projection of the lashes. As a consequence there will be a difference in the size of the retinal images in the two eyes. Another important reason is the difference in prismatic effect of the two lenses when the visual axis is directed obliquely through them. The result is an artificial heterophoria, so that when looking downwards at the book a vertical diplopia is produced, with all the troublesome symptoms of a hyperphoria.

In the higher degrees of anisometropia the eyes are frequently used alternately, one eye being myopic and the other emmetropic or hypermetropic. Such patients do not suffer from asthenopia, as there is no attempt at binocular vision, and one eye is used for near objects and the other for distant. These patients have not binocular vision, and cannot use the full correction constantly.

For near work, however, glasses may sometimes be used by averaging the difference between the two eyes. This may be done by making each eye artificially presbyopic by the amount equal to half the difference in the refraction between the two eyes. Thus, in a patient with 1 D of hypermetropia in one eye and 2 D of myopia in the other, a pair of spectacles with a $+ 1{\cdot}5$ D sph in front of the hypermetropic eye and $- 1{\cdot}5$ D sph in front of the myopic eye may be ordered for near use.

In all cases of anisometropia in young people, an attempt should be made to use correcting lenses, so as to develop and retain binocular vision; in adults attempts will usually fail. In cases of constant squint, the correcting glasses should be worn, accompanied by exercises with a view to regaining vision in the amblyopic eye.

Aphakia.—In aphakia the lens has been removed from the eye. It is the condition found after the removal of a cataract, and in those rare conditions in which it has been necessary to remove the lens in high myopia.

The result is that one of the chief refracting media of the eye has been removed, and the dioptric value of the eye reduced by that amount; in the previously emmetropic eye a condition of high hypermetropia has resulted, and if the eye were previously myopic, it will now be less myopic, or even slightly hypermetropic.

The optic system of the eye is now extremely simple, consisting merely of a single convex surface, the cornea, bounding a medium whose refractive index is 1·337.

The radius of curvature of the cornea is 8 mm., and the index of refraction of the air 1, the medium outside the eye. The formula for the anterior focus is:

$$F' = \frac{-\mu' r}{\mu'' - \mu'}$$

$$= \frac{8}{1{\cdot}337 - 1} = 23{\cdot}774 \text{ mm.}$$

for the posterior focus:

$$F'' = \frac{\mu'' r}{\mu'' - \mu'}$$

$$= \frac{1{\cdot}337 \times -8}{1{\cdot}337 - 1} = -31{\cdot}774 \text{ mm.}$$

and so the anterior focus of the eye is 23·774 mm. in front of

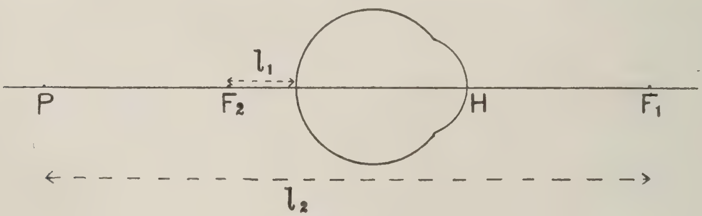


Fig. 105.

the cornea, and the posterior focus 31·774 mm. behind the cornea, that is, about 8 mm. behind the retina in a previously emmetropic eye.

An aphakic eye which was previously emmetropic is highly hypermetropic, so that its punctum remotum will be behind the eye. Let P be the punctum remotum of such an eye in Fig. 105. Then rays converging towards P will come to a focus on the retina. In other words, P and a point on the retina will be conjugate points in the refractive system, and if P be at a distance l_2 from the first principal focus F_1, and the retina be at a distance l_1 from the second principal focus F_2, then $l_1 l_2 = F'F''$, and l_2 can be calculated.

Thus
$$l_2 = \frac{F'F''}{l_1}$$
$$= \frac{(23{\cdot}774)\,(-\,31{\cdot}774)}{8}$$
$$= \frac{-\,755}{8} = -\,94{\cdot}4 \text{ mm.}$$

That is, the punctum remotum is behind the eye at a distance of 94·4 mm. from its anterior principal focus, and a lens having a focal length of — 94·4 mm., placed at the anterior principal focus, will cause parallel rays to come to a focus on the retina. This correcting lens will have a dioptric strength of $\frac{1{,}000}{94{\cdot}4}$ or 10·6 D.

As glasses are worn at 13 mm. in front of the cornea, a lens of slightly less focal length, and, consequently, higher dioptric value, is required.

When a lens, in axial ametropia, is worn at the anterior principal focus of the eye, the distance of the retina from the nodal point of the eye remains the same, and so the size of the image remains the same.

The distance N of the nodal point from the retina is 15·54 mm., whereas in aphakia the distance is 20·69 mm.

$$\frac{i'}{i} = \frac{N'}{N} = \frac{20{\cdot}69}{15{\cdot}54} = 1{\cdot}33,$$

thus showing that the image in corrected aphakia is about one-third larger than in the emmetropic eye. The tests for visual acuity are not really comparable as 6/12 in emmetropia is equivalent to 6/9 in corrected aphakia.

This disparity in size of the retinal images explains how it is that a patient who has one good eye is not benefited by an extraction of a cataract in the fellow eye, as he is unable to fuse images of different sizes.

After extraction of a cataract by an incision at the limbus in the usual way, a certain amount of astigmatism against the rule is produced, owing to the flattening of the cornea in the vertical meridian, during the healing of the wound. The amount is usually about 1·5 D, but may be greater, and as this amount tends to diminish rapidly in the weeks following the operation, the final glasses should not be given until at least six weeks have passed.

Anomalies of Accommodation.—*Presbyopia.*—When discussing the mechanism of accommodation we saw that the power of focussing the eyes for objects nearer than infinity, the dynamic refraction of the eye diminished as age advanced, and that whereas at the age of eight years the average amplitude was 14 dioptres, in old age no accommodation for near objects remained. This gradual loss of the power of accommodation is physiological as well as the hypermetropia that is acquired in old age, both conditions being directly due to sclerosis of the lens producing, on the one hand, an inelastic lens that will not respond adequately to a given contraction of the ciliary muscle, and on the other, such a high index of refraction of the cortex, that the dioptric value of the lens as a whole is reduced.

When the near point of accommodation has receded to 28 cm., the condition is known as presbyopia. This arises in the emmetrope about the age of forty-five years, but necessarily earlier in the hypermetrope, and later in the myope, depending upon the amount of static refractive error. In the myope whose error is 4 D, presbyopia will never arise.

Most of our work at near range is carried on at a distance of 25 cm., reading, writing, and the rest, so that we find it necessary to exercise 4 D of accommodation for long periods during the day. At the age of forty-five years, the average amplitude of accommodation is 4 D, so that in an individual who is

emmetropic, it is necessary to exert the whole of the accommodation to maintain useful near vision. In consequence, especially later in the day, difficulty is experienced in reading at 25 cm., and the book is held farther away, the letters forming smaller and smaller angles at the nodal point of the eye until in a few years reading is impossible with books printed in ordinary type.

Experience shows that we must have about 0·5 D of accommodation in reserve, so as to work comfortably at a distance of 25 cm., and when the accommodation has fallen to 4 D, then we must give assistance to the eyes by using convex glasses of appropriate strength. The accommodation which remains, together with the convex glass prescribed, must never exceed 4·5 D; therefore, considering that at each year of life there is a maximum and minimum amplitude of accommodation, when large numbers of individuals are examined, we must not order reading glasses merely by rule of thumb. Each patient with presbyopia must be examined to find the amplitude of accommodation that remains, that is, his near point must be measured whilst wearing the glasses that correct his ametropia, and the figure found supplemented by a convex lens, so as to bring the punctum proximum to 22 cm., in other words, to render the sum of accommodation and spectacle lens equal to 4·5 D.

The reason why such great care should be taken not to give a lens of too high a power is that with a lens of too great dioptric value we upset the balance between accommodative effort and convergence.

It is, at first sight, remarkable that patients with presbyopia find comparatively little difficulty in maintaining the convergence necessary at near range, since it would appear that a patient who requires a + 3 D lens to read at 25 cm., exerts but 1 D of his accommodation, but yet must converge the visual axes 4 metre angles in each eye. The explanation is supplied by the following reasons, which are summarised from Fuchs' observations:

Recession of the punctum proximum due to sclerosis of the lens has little to do with any impairment of power of the ciliary

muscle, which is easily understood when we remember that when the muscular power of the body is at its greatest, the accommodative power is less than that of the young child. It is likely that the actual contractile power of the ciliary muscle of the man of forty years (when the punctum proximum is 17 cm.) is as good as that of the boy of ten years, with a punctum proximum of 7 cm., that is, when focussing a near object, both exert an equal amount of muscular power, but, of course, with very different results upon the dioptric value of the intraocular lens, and that whereas their *physiological near points* are the same, their *physical near points* are very different.

When we come to deal with the presbyopic individual, the *physiological accommodation* does not necessarily correspond with the *physical accommodation.* Thus an individual who has but 1 D of accommodation remaining, is able to read at a distance of 33 cm. with suitable glasses. It would seem that he need only contract his ciliary muscle sufficiently to produce the effect of 1 D in the intraocular lens, yet it is probable that his effort of contraction of the ciliary muscle is sufficient to add + 3 D to the intraocular lens if it were in such a physical state as to respond to such an effort, that is, he contracts his ciliary muscle in accordance with the stimulus set up by the convergence, rather than to accord with the effect on the lens that the convergence is designed to produce.

Paralysis of Accommodation.—*Cycloplegia.*—The result of paralysis of the accommodation is an extreme loss of the power of focussing near objects, a great reduction in the amplitude of accommodation. When the accommodation is very deficient there may be some difficulty in measuring whatever may remain owing to the patient finding it impossible to see very small print or the hairs of the optometer or similar device that we may use. To overcome this difficulty, first of all find the lens that corrects any ametropia present, and so render the eye emmetropic, then if the smallest near type cannot be read add a + 4 D sph to the correction in the test frame. This in complete paralysis will bring the punctum proximum to 25 cm. Suppose it to bring the punctum proximum to 20 cm., this being the

focal length of a + 5 D sph lens, shows that with the + 4 D sph. the total accommodation is 5 D, and, therefore, the eye itself is exerting 1 D of accommodation.

Paralysis of the accommodation is due to paralysis of the ciliary muscle, and it may exist by itself as a sole symptom or be associated with paralysis of the sphincter of the pupil (the more common condition) in ophthalmoplegia interna, or it may be part of a complete paralysis of the third nerve.

Apart from difficulty in vision at a near range, patients with paralysis of accommodation complain of micropsia, that is, objects appear smaller than usual. This is due to an increased effort of accommodation, leading the patient to suppose that an object is nearer than it really is, but the retinal image is not increased, and so he imagines that the object has diminished in size.

The causes of paralysis of the accommodation are :

1. *Toxic.*—Diphtheria is the commonest cause, the paralysis appearing about the sixth week after the onset of the disease, which may not be very severe. Not infrequently the ciliary muscle alone is paralysed, the sphincter pupillæ being spared. The soft palate is frequently affected at the same time as the ciliary muscle. Influenza is sometimes a cause, as well as diabetes and ptomaine poisoning.

More recently paralysis of the ciliary muscle, with or without paralysis of the sphincter pupillæ, has been found in encephalitis lethargica, in which it is likely to remain permanent, whereas in other diseases the power of accommodation is gradually recovered.

Toxic paralysis is usually bilateral.

2. *Drugs.*—Certain drugs cause paralysis of accommodation. The cycloplegia is always accompanied by mydriasis, and may be unilateral. (*See* p. 140.)

3. *Cerebral syphilis*, as well as tabes dorsalis and general paralysis.

The condition is often unilateral and accompanied with mydriasis, and not infrequently with paralysis of the third nerve.

4. *Contusion of the eye.*

Weakness of the accommodation is not infrequently seen after a severe illness, and it may be many months before full power of the muscle is regained. It is one of the causes of asthenopia, and will be diagnosed when we find that the amplitude of accommodation does not correspond to the age of the patient. These cases we may help by prescribing reading glasses that bring the punctum proximum to a useful distance.

In the early stages of glaucoma, weakness of accommodation is seen, and a rapidly advancing presbyopia, especially out of proportion to the age of the patient, should arouse suspicion.

Spasm of Accommodation.—Genuine spasm of accommodation is uncommon, and it is usually produced by an uncorrected error of refraction in eyes that have been used for prolonged periods for near work in a bad light.

We have seen that there is a normal physiological tone of the ciliary muscle, which is revealed by the use of atropine, and which has a value of about 1 dioptre. The use of atropine sometimes causes a greater effect, showing that there has been spasm of the ciliary muscle.

The condition is more often seen in myopia, and we are made aware of its presence when the patient accepts a higher concave lens when examined subjectively than we have found by objective examination.

The use of eserine produces spasm of the ciliary muscle.

Spasm of accommodation associated with spasm of convergence is found in hysterical patients.

Cycloplegics and Mydriatics.—Drugs that dilate the pupils and paralyse the accommodation are used with such frequency in estimating the refraction of the eye that it is of importance that we should have some detailed knowledge of their action.

Both properties are of use, since the dilated pupil allows observations, both in ophthalmoscopy and retinoscopy, that are difficult or impossible when the pupil is small, and the cycloplegic action allows an estimation of the static refraction of the eye which may otherwise be difficult in an adult, and impossible in a young child.

It must be borne in mind that a dilated pupil exposes portions of the lens that are not used in ordinary vision through the pupil of natural size, and as the eye suffers, in common with all other optical instruments, from spherical aberration, care must be taken in estimating the refraction, especially by retinoscopy, that our observations are confined to the central parts of the system, which alone are uncovered by the natural pupil, an area not greater than 4 mm. in diameter. It is for this reason that we have impressed upon the observer, in the chapter on retinoscopy, that the central part of the light reflex in the dilated pupil alone should be observed and no attention paid to the peripheral reflex.

It may not be out of place to impress upon the student that the tension of the eyes and the condition of the pupils must be observed before mydriatic drugs may be applied with safety.

The following are the drugs in common use in estimating the refraction of the eye :

Atropine. — This is the most powerful cycloplegic and mydriatic we possess, and a single drop of a 1/45,000 solution will dilate the normal pupil. It is commonly used in two forms :

1. A watery solution of the sulphate of atropine of the strength 1 per cent.

2. A solution of the alkaloid in soft paraffin (yellow), also of the strength 1 per cent.

A single drop of the watery solution dilates the pupil in fifteen minutes, and a few minutes later begins to paralyse the accommodation. The action on the ciliary muscle is slow, and paralysis is not complete for at least two hours. It requires frequent application to produce complete paralysis such as is required for estimation of refraction, and, especially in young people with a powerful accommodation, the drug must be used three times daily for at least three days.

It must be remembered that atropine is a poison, even when used in small quantities as drops for the conjunctival sac, and so the ointment of atropine is to be recommended as a safer application, especially in children. The ointment is also more

efficacious, as it is more likely to remain in the conjunctival sac than the watery solution, and so to act continuously.

Care must be taken that no ointment is used for several hours before the examination, lest the cornea be rendered so greasy that its transparency and regular refraction are interfered with.

Atropine used in the way indicated will cause paralysis of the ciliary muscle for from seven to twelve days, and dilatation of the pupil for even a longer period. This is the great objection to its use, especially in adults, as no drug can overcome its action, and the patient is unable to read normally for many days, and in certain cases the risk of glaucoma is run so long as the pupils are dilated.

Homatropine.—This drug, commonly used in the form of homatropine hydrobromide, has similar properties to those of atropine, but has the advantage of being more rapid in the disappearance of its action, as well as being easily controlled in its action by eserine.

It is commonly used in two forms :

1. As a watery solution, of a strength 1 per cent. of the hydrobromide.

2. As a solution in castor oil of a mixture of the alkaloids of homatropine and cocain, 2 per cent. each.

The oily solution has the advantage of not being washed out by the tears, and, consequently, requiring but one application in a given case of refraction.

With such an application the pupil will begin to dilate from the fifth to the twentieth minute, will reach its maximum from the thirtieth to the fiftieth, and will become normal again in from fifteen to thirty-six hours.

In a particular case the recession of the punctum proximum, which began between the fifth and fifteenth minute, reached its maximum between the thirtieth and eightieth minutes, and disappeared in from six to twelve hours.

It is found that the mixture of homatropine and cocain dilates the pupil more rapidly than when homatropine alone is used, and its effect lasts longer. Similarly its effect on the

punctum proximum lasts longer, and the accommodation is practically reduced to *nil* by its influence.

A drop of the watery solution will cause dilatation of the pupil in fifteen minutes, and if the application is repeated every fifteen minutes, will, in an hour, cause almost complete paralysis of the accommodation. The effect on the accommodation will have passed in from six to twenty-four hours sufficiently to allow near use of the eye, and in fifty hours completely.

Apart from the rapid recovery of the accommodation after an application of homatropine, a further advantage in its use is that its action can rapidly be overcome by the subsequent use of eserine, which has no effect upon the action of atropine. Thus a dilatation of the pupil which began between the fifth and fifteenth minutes reached its maximum between the fifteenth and ninetieth minutes, after the application of homatropine and cocain. The application of eserine between the fiftieth and ninety-fifth minutes caused a contraction of the pupil, which began in five to fifteen minutes and reached its maximum in from thirty-five to fifty-five minutes, leaving the pupil slightly smaller than before the application of the homatropine and cocain.

The recession of the near point, which began between the fifth and tenth minutes, reached its maximum between the thirty-fifth and seventy-fifth minutes, and was then equivalent to 5·37 D to 7·62 D. The application of eserine between the fiftieth and ninety-fifth minutes caused an approximation, which began in five minutes and reached its maximum in twenty-five to forty minutes, and was then equivalent to 4·57 D to 7·68 D, so that the punctum proximum was actually nearer than before the application of homatropine and cocain.

Therefore, after paralysis of the constrictor pupillæ and ciliary muscle by homatropine or homatropine and cocain, the application of eserine causes a contraction of the pupil, and an approximation of the punctum proximum, so that in the majority of cases the individual can resume near work in a few minutes without inconvenience.

When an eye has recovered from the action of a cycloplegic it will be found that the lens that gave full vision with the accommodation paralysed is no longer accepted, but if it be a case of hypermetropia a somewhat lower power of lens is the one chosen by the patient. The actual amount of reduction necessary to give good vision varies with different patients, but as a rule the eye will accept a lens of 1 D less power in a case of hypermetropia when the accommodation has recovered from the effects of atropine, and 0·75 D less in the case in which homatropine has been used.

It must be remembered that when the accommodation is fully relaxed there still remains a certain amount of physiological tone in the ciliary muscle which produces relaxation in the fibres of the suspensory ligament of the lens, and so causes the lens to be more convex than when the tone of the muscle is temporarily destroyed by the use of a cycloplegic. The dioptric value, so to speak, of this tone is, with the use of atropine, + 1 D, and with homatropine, a less powerful drug, + 0·75 D.

In the case of myopia it is not always necessary to make this allowance, or at any rate not one of such large amount as in hypermetropia ; the ciliary muscle is less developed in myopia than in hypermetropia (where it may be of excessive size and power), so that not more than 0·50 D should be allowed for muscle tone, and in most cases nothing at all.

CHAPTER V

THE OPHTHALMOSCOPE

In ordinary circumstances the pupil of the eye appears black, the explanation of which remained obscure until the middle of the nineteenth century. From the fact that in albinoes the pupil appears red, it was assumed that the choroidal and retinal pigment in the normal eye absorbed all the light that entered it, and that it was only when this pigment was absent in the albino that any kind of view of the fundus of the eye was possible.

This explanation is based upon an erroneous interpretation of the facts. The reason why the pupil of the albino gives a red appearance is not due to the absence of pigment to absorb any light that may enter the eye through the pupil, but is due to the fact that light enters the eye not only through the pupil, but also through the iris and sclera, which by the absence of uveal pigment are rendered semi-transparent. This was proved by Donders, who showed that when an opaque diaphragm with a hole the size of the pupil was placed in front of an albinotic eye so that the hole coincided with the pupil, the pupil appeared black as in eyes with the normal amount of pigment. The explanation, then, of the blackness of the pupil is that very little light can enter the eye through the relatively small opening in the iris, that the light is not absorbed entirely by the uveal pigment, but is reflected back through the pupil in the same direction as that by which it entered and so could only be appreciated by an observer if his own pupil happened to coincide with the path of this narrow bundle of rays of light

It must have been noticed from the remotest times that the eyes of certain animals, especially carnivora and nocturnal animals, give out a bright reflex in the dusk. This was explained by assuming that the eyes of these animals emitted light at

night like the bodies of glow worms, and that it was useful to them in searching for their prey in the dark. Prevost, in 1810, showed that this glow never occurred in complete darkness, that no irritation of the animal produced it, and that it was

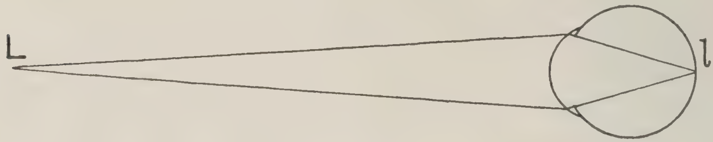


FIG. 106.

due to the reflection of incident light. Gruithuisen, after confirming this observation, showed that the glittering was due to the reflection of light from the tapetum, a portion of the choroid, the retinal surface of which is highly polished, and stated that he had seen the reflex in dead animals. A similar glow had been noticed in the human eye in certain diseases, especially when a tumour occupied the fundus of the eye, and Beer, in 1839, remarked the glow in certain cases of aniridia, and also that the eyes of the observer must look at those of the observed in a direction nearly parallel to that of the incident rays.

Brücke and W. Cumming, in 1847, found, independently of each other, a method of rendering the normal human eye luminous when the observer looked nearly parallel to the direction of the incident rays. Brücke originally tried the method on various animals who possessed a tapetum in a zoological gardens, and was led to try the experiment on the human eye by remembering that when he was a boy his father had dismissed a servant owing to the unpleasantness of seeing his eyes shining in the dusk. Brücke first tried the experiment on the eyes of Du Bois Reymond.

The accompanying diagram shows the method employed. In a dark room a light L is held in front of the observed eye. The observed eye must not accommodate for the light. A circle of diffusion illuminates the retina, which reflects rays back not only to the source of light, but also in other directions in

the form of a cone. The observer's eye held to one side of the source of light, and protected by a screen from its direct light, will receive some of the rays reflected from the fundus of the

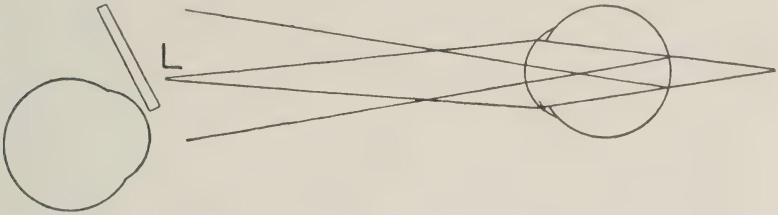


Fig. 107.

observed eye. This experiment will only succeed if the observed eye be hypermetropic or strongly myopic. In the case of an emmetrope the rays are reflected so as to leave the eye in a parallel direction, and then the observer can only receive them if his eye coincides with the path of the incident rays.

Although the fundus could be illuminated and made visible by this means, details of its structures could not be seen, and the reason for this gave rise to much discussion. As early as 1704, Mery observed that he could see the vessels in the retina of a cat's eye when its head was immersed in water. In 1709, de la Hire, commenting on this observation, stated that the water abolished the refraction of the cornea, and so apparently brought the cat's retina nearer to the eye of the observer, the view of the fundus being facilitated by the dilatation of the cat's pupil, which allowed a better illumination of the interior of the eye.

From the experiment of Brücke it was shown that in order to see the fundus of an eye of any refractive power it was necessary to bring the eye of the observer into the path of the rays reflected from the eye without obscuring the rays from the source of light illuminating the interior of the eye. If the eye were accommodated for the source of light, the retina and the light then became conjugate foci, and unless the eye of the observer coincided with the source of light no details of the fundus could be seen (Fig. 106). This is

apparent from the diagram, in which L is the source of light, and l the image of the source formed by the accommodation of the eye.

Helmholtz was the first to give a complete account of the relation between the incident and emergent rays, and a true explanation of the blackness of the pupil.

He used, to illuminate the fundus, the virtual image of the source of light formed in a glass plate and was in this way able to place the observer's eye behind the glass plate so as to intercept some of the rays which were reflected by the fundus of the observed eye, and passed through the plate of glass.

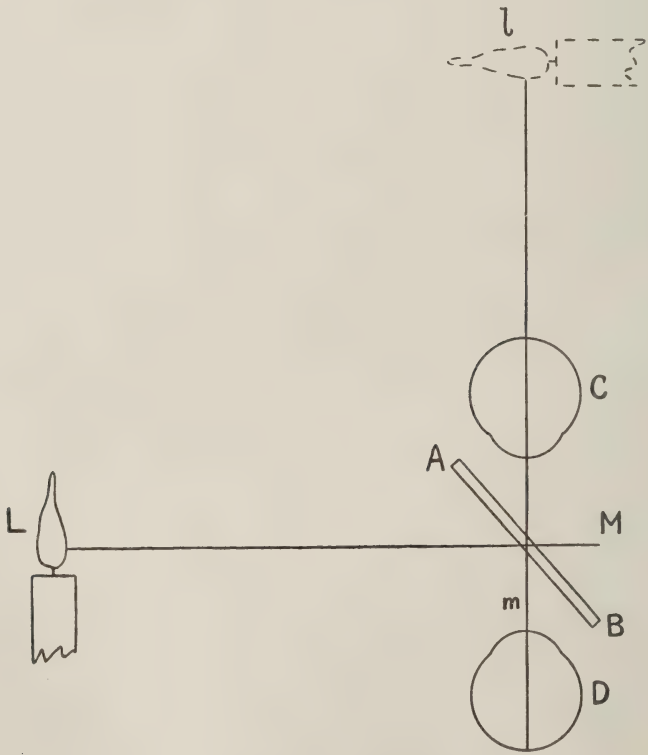


FIG. 108. (Helmholtz.)

The arrangement is shown in the diagram.

L is the source of light, and AB the glass plate : the greater part of the rays of light will pass through the plate in the direction M and so be lost, others will be reflected in the direction *m* as if they had come from the virtual image of L, in the position *l*. If the observed eye D be placed so as to receive the rays reflected by the plate, and the observer's eye C be placed behind the plate, C will, in this position, be able to receive rays reflected from the fundus of D, which pass through the plate AB in the direction of *l*. Some of the rays from D will be reflected back to L, and thus will be lost.

Provided the observed eye and that of the observer be emmetropic, that is, the observed eye emitting parallel rays and the observer's focussed for parallel rays, it will be possible to see the details of the retina of the observed eye.

As it is necessary for both the observer's and the observed eye to be emmetropic and in a state of relaxation of the accommodation, it would seldom be possible to obtain a clear view of details of the fundus. Helmholtz solved this practical problem by placing before the observer's eye a plano concave lens, and by this method was able to obtain a magnified erect image of the fundus.

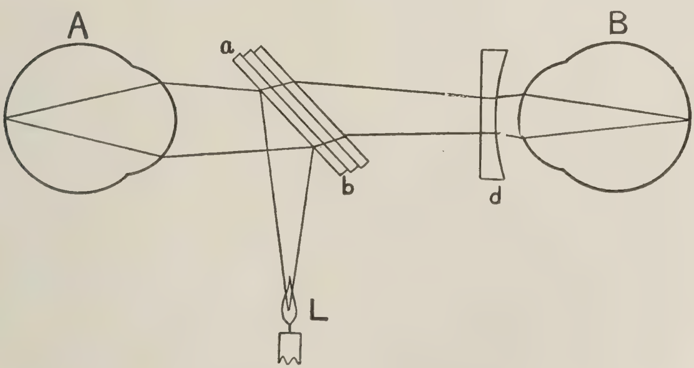


Fig. 109. (Helmholtz.)

In this diagram A is the observed eye and B the observer's, L the light and *ab* the superimposed plates acting as a mirror.

The rays reflected from the retina of A will leave the eye in a convergent direction depending upon the refraction of the eye. These rays are made, by the lens *d*, held nearer to or farther away from B, to take such a direction that the eye B is able to accommodate and so bring the rays to a focus upon its retina. This arrangement is essentially that of Galileo's telescope, the lens system of the observed eye being the objective, and the plano concave lens the eye-piece.

The above method is known as the direct method of ophthalmoscopy, the examination of the erect image of the retina.

In 1852 Reute improved upon the plates used by Helmholtz as a mirror, by introducing a concave silvered mirror from a portion of which the silvering had been removed, and also described another method of using the ophthalmoscope based on the principle of the Kepler's or astronomical telescope.

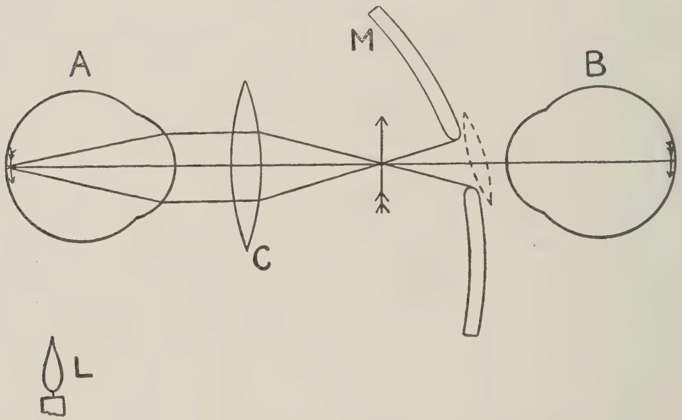


Fig. 110. (Helmholtz.)

The principle is shown in the diagram in which A is the observed eye, B the observer's, and L the source of light. The rays are reflected into the eye by the concave silvered mirror M, and after leaving the eye are made to come to a focus in front of the observed eye by the interposed lens C, of short focal length. Thus an aerial inverted image is formed between the

mirror and lens for which the observer's eye B is accommodated, aided, if necessary, by a suitable lens placed behind the sight hole of the mirror.

This method is known as the indirect method of ophthalmoscopy, or the examination of the inverted image.

THE DIRECT METHOD. EXAMINATION OF THE ERECT IMAGE.

1. **In Emmetropia.**—Rays emitted by an emmetropic eye are parallel in direction, and the image formed by them is at infinity : this is what we mean when we say that the punctum remotum, or conjugate focus of the retina of the emmetropic eye is at infinity. These rays produced behind the eye will give a virtual erect image of the retina at infinity, and in front of the eye, a real inverted image at infinity.

If in front of such an eye, another emmetropic eye be placed, or an eye rendered emmetropic by a suitable lens, these rays will come to a focus upon the retina of the second eye, giving an image of the retina of the first eye when the accommodation of each eye is at rest, that is, when both eyes are in a state of static refraction.

To the second eye, that of the observer, the rays will appear to have come from an enlarged virtual erect image behind the first, or observed eye.

Let A be an emmetropic eye, and *ab* a small area on the retina. Let XY be the optic axis, and the point *a* lie upon it. As when constructing images formed by a convex lens, to find the image of a point on the retina it will only be necessary to consider two rays, namely, one parallel to the axis, which will after refraction pass through the anterior focus, and another ray, a secondary axis, which will pass through the nodal point, or optic centre, and so out of the eye without refraction.

Taking the point *b* draw two rays, one *bd* parallel to the optic axis which will pass through *F* and *bN* which will pass out of the eye parallel to *dF*, having undergone no refraction. These rays projected behind the eye A will meet in *b′* giving an image of the point *b* at infinity. Since *a* is on the optic axis, *a′* will also be found on the optic axis, and as *ab* is at right angles to the optic axis, *a′b′* will also be at right angles to the optic axis.

Imagine the emmetropic eye B placed in front of A so that their anterior foci, FF', and also their optic axes coincide.

The virtual image $a'b'$, of the object ab, serves as the object for which the eye B is adapted.

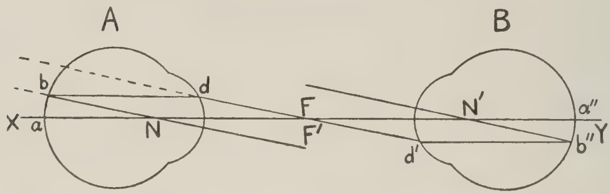


Fig. 111.—The Direct Method in Emmetropia.

The ray $b'Fd'$ will after refraction by B be parallel to the optic axis, and the ray $b'N'$ passing through the nodal point will be unrefracted. These rays will meet in b'' and here will be the image of b', and since a' is on the optic axis, so also will be a'', $a''b''$ being at right angles to the optic axis, and the real inverted image of $a'b'$, and, therefore, of ab.

In the triangles aNb, $a''N'b''$,

$aN = a''N'$.

The angle at $N =$ that at N',

and so $a''b'' = ab$.

The use of the ophthalmoscope in emmetropia is comparable to the use of a simple magnifying glass in which the object is at the principal focus of the lens. (*See* p. 157.)

2. **In Hypermetropia.**—Rays emitted from the retina of a hypermetropic eye are divergent in direction, and, when prolonged backwards, meet in a point behind the eye at a distance less than infinity, giving here an enlarged virtual image of the retina. This image, as we have seen in the emmetropic eye, will act as the object for an eye placed in front of such an hypermetropic eye.

Let A be a hypermetropic eye and ab a small area on the retina, let XY be the optic axis and the point a lie upon it.

Taking the point b draw two rays, one bd parallel to the optic axis which will pass through F, and bN which will pass out of

the eye divergent without undergoing refraction. These rays prolonged behind A will meet in b', giving here an image of b. Since a is on the optic axis, a' will also be found here, and as ab is at right angles to the optic axis $a'b'$ will also be at right angles to the optic axis, and will be the image of ab.

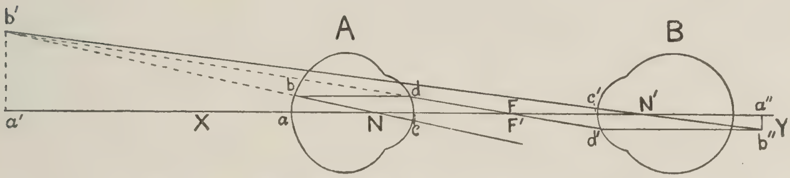


Fig. 112.—The Direct Method in Hypermetropia.

Imagine an emmetropic eye B placed in front of A so that their anterior principal foci, FF', and also their optic axes coincide.

The virtual image $a'b'$ of the object ab serves as the object for the eye B. We have seen that rays from b' are divergent in direction.

The ray $b'Fd'$ will, after refraction by B, be parallel to the optic axis, and the ray $b'N'$ passing through the nodal point will be unrefracted. These rays will meet in b'', and here will be the image of b', and since a' is on the optic axis, so also will be $a,''a''b''$ being at right angles to the optic axis and the real inverted image of $a'b'$, and, therefore, of ab.

Again the image $a''b''$ is the same size as ab.

In the triangles dFc, $d'F'c'$

$$cF = c'F'$$

The angle at F = that at F', and so

$$dc = d'c',$$

but $$ab = dc = d'c' = a''b''$$

$\therefore$ $$a''b'' = ab.$$

The virtual image $a'b'$ being distant from the eye B less than infinity, and the eye B being focussed only for parallel rays, the image $a''b''$ must, therefore, fall behind the retina of B, so that to form an image on the retina of B, it is necessary either for B to accommodate for $a'b'$, or for a convex lens to be placed

between A and B of such focal length, that its principal focus coincides with $a'b'$, and so render the rays from $a'b'$ parallel.

Let B accommodate for $a'b'$ the virtual image of ab.

As a result of accommodation, the refractive power of B is

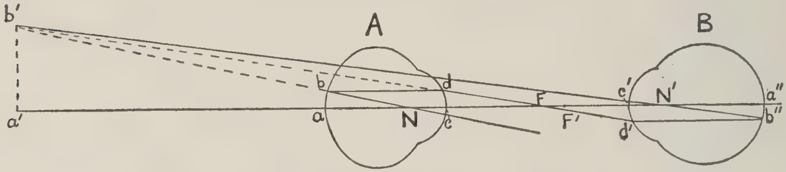


Fig. 113.—To show the effect when B accommodates for $a'b'$.

increased, and, therefore, its anterior principal focus F' will no longer coincide with F, but will approach the eye B. The ray $b'\,F$ will no longer pass through F', but will cut the optic axis remote from this point. The ray $d'b''$ will no longer be parallel to the optic axis, but will be convergent as we pass from d' to b'', and as we have shown above

$$d'c' = dc = ab$$

since $\quad a''b''$ is less than $d'c'$

$\quad a''b''$ is less than ab.

The image formed on the retina of B is, therefore, smaller than the object ab.

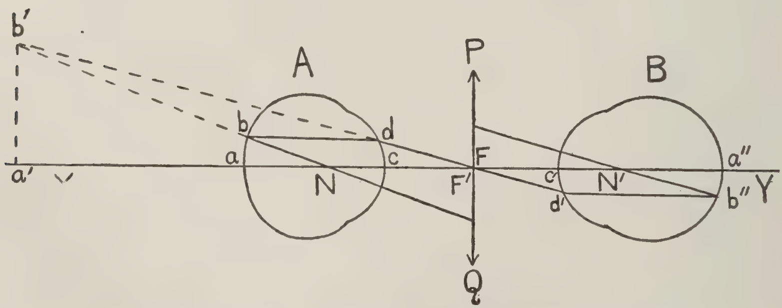


Fig. 114.—To show the effect of a correcting lens at F and F'.

With the observing emmetropic eye at rest, the divergent rays from the observed hypermetropic eye may be made

parallel by placing a suitable convex lens so that its optic centre coincides with the two anterior focal points of the eyes under consideration. The use of a convex lens will be the only possible way to obtain a distinct view of the hypermetropic fundus when the accommodative power of the observing eye is insufficient to bring the divergent rays to a focus.

The focal length of this lens will be such that its principal focus coincides with $a'b'$, the virtual image of ab. This image $a'b'$ now becomes, in relation to the lens PQ, an object placed so that the image formed by the lens will be at infinity, and thus the rays from each point of $a'b'$ will emerge from the lens in a parallel direction.

Now $c'd' = a''b''$ and $cd = ab$.

Since $c'd' = cd$ then $a''b'' = ab$.

We are thus able to produce upon the retina of the observing eye an image equal in size to the object on the retina of the observed eye.

This relation will only exist when the optic centre of the lens coincides with the anterior focus of the observed eye.

3. **In Myopia.**—In myopia rays leave the eye in a convergent direction and will, if extended, form an image of the fundus of the eye at its punctum remotum or conjugate focus between the eye and infinity. This image will be real and inverted.

Let A be a myopic eye and ab a small area on the retina; let XY be the optic axis and the point a lie upon it.

Taking the point b, draw two rays, one bd parallel to the optic axis which, after refraction, will pass through F, the anterior focus, and another bN, which being a secondary axis will leave the eye convergent without undergoing refraction. These rays prolonged in front of A will meet in b', the image of b. As a is on the optic axis it will be found here also after refraction, and as ab is at right angles to the optic axis $a'b'$ will also be at right angles, and so $a'b'$ will be a real inverted image of ab.

Let B be an emmetropic eye placed in front of A so that

their anterior principal foci, FF', and also their optic axes coincide.

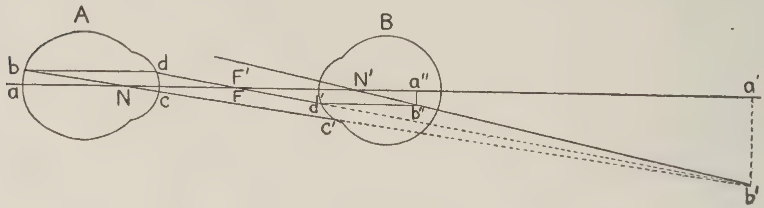


Fig. 115.—The Direct Method in Myopia.

The real image $a'b'$ of the object ab serves as the virtual object for the eye B. The ray N$'b'$ being a secondary optic axis will pass through B unrefracted. The ray F$'d'b'$ passing through the anterior principal focus of B, will on refraction by B have a direction $d'b''$ parallel to the optic axis, cutting N$'b'$ in b'', the image of b' and therefore of b.

Since a is on the optic axis it will be found here also after refraction, and since ab is at right angles to the optic axis, the image of ab will be at $a''b''$. This image formed in front of the retina of B will be the same size as ab, as has been shown in considering the formation of images in emmetropia and hypermetropia.

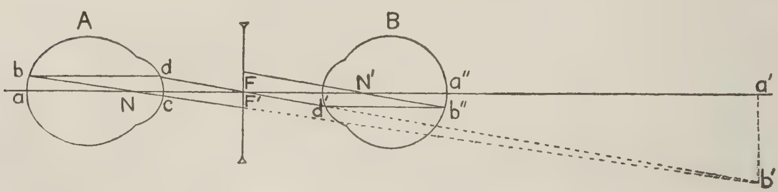


Fig. 116.—To show the effect of a correcting lens at F and F'.

The eye B cannot by any means focus the image $a''b''$ upon its retina, and hence it is necessary to place a concave lens at F between the eyes of A and B, of such a strength as to render parallel the convergent rays from A. This lens will have its principal focus coincident with $a'b'$, and by its action will cause

an image $a''b''$ to fall on the retina of B, which will be equal in size to the object ab, as has been shown to be the case in hypermetropia corrected by a lens.

Magnification of the Image in the Direct Method.—The image of the portion of the retina observed by the direct method is magnified, and the magnification is the proportion that the size of this image as seen by the observing eye bears to the size of the object.

When using a convex lens as a magnifying glass, the greatest magnification that can be obtained is when the object is placed at the principal focus; as a result, the rays, after passing through the lens, are parallel in direction, and when received by the eye are projected backwards through the lens to a point behind it at the minimal distance of distinct vision. When viewing the fundus of an emmetropic eye the conditions are similar, as the rays leave the eye in a parallel direction, and thus come to a focus upon the retina of the observing emmetropic eye, and are then projected behind the observed eye to the minimal distance of distinct vision. (*See* p. 92.)

This distance is necessarily arbitrary, but since the distance at which we hold objects near at hand is about 25 cm, this is, therefore, taken as the minimal distance.

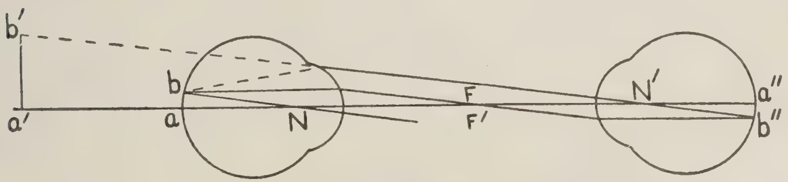


FIG. 117.

In this figure $a''b''$ is the image formed on the retina of an emmetropic eye by the area ab on the retina of the observed emmetropic eye. The image and object we have shown to be equal. The eye B projects the object ab to the position $a'b'$ at a distance of 25 cm. in front of its own nodal point N'. Draw the secondary axis $b''N'b'$.

We have thus two triangles,

$$a''N'b'' \text{ and } a'N'b',$$

which are similar, the angles at N' being equal, the sides $a''b''$ and $a'b'$ being parallel.

$$\therefore \qquad a'b' : a''b'' :: a'N' : a''N'$$

$$\frac{a'b'}{a''b''} = \frac{250}{15}$$

$$= 16{\cdot}5$$

Thus the diameter of the optic disc in the direct method is 12·5 mm.

In emmetropia, E, the posterior focus of the eye is on the retina. In hypermetropia, H, the retina is situated in front of the principal focus. For this to happen it may be that the axis of the eye is too short (H.A.), it may be that the refracting power is too weak, and as a result the focal distance too great (H.R.). In general, and always in the high degrees, hypermetropia is axial in origin.

Myopia, where the retina is behind the posterior focus, may equally be of axial origin (M.A.) or due to excess of refracting power (M.R.). In general, and especially in high degrees, it is due to lengthening of the axis.

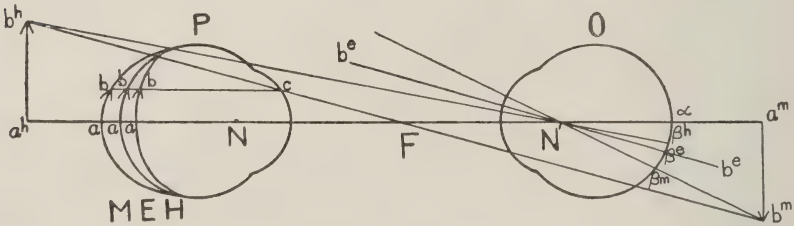


FIG. 118. (Bjerrum.)

The magnification of the ophthalmoscopic image in H.R. and M.R. will be studied in the chapter on astigmatism (see further on) where it has a great practical importance. Here we will consider the magnification in H.A. and M.A. as compared with that in emmetropia. We set out with the hypothesis that the refractive power is the same in E., H. and M., that the length only of the antero-posterior axis of the eye varies.

The optic centre of O will always be further from P than

F, the anterior focus of P. In this case, the angle under which an object on the fundus of the eye P is seen will appear greater when the fundus is situated behind the posterior focus of P.

Let ab be a part of the fundus of the eye of equal extent in the short eye (H), the mean eye (E), and the long eye (M).

The ray bc parallel to the optic axis will pass, after refraction at its exit from the eye, through F, the anterior principal focus of P. The image of b formed by the refractive media will be found in the three cases on the line cF or on its prolongation backwards (the point where the image is formed is determined by the intersection of the line cF with the secondary optic axis Nb) in M at bm, in E at ∞, in H at bh. The image a is found on the principal optic axis aN, respectively at am, ∞ and at ah. If we draw the lines bmN′, beN′, and bhN′ (the line beN′ being considered as coming in emmetropia from a point be situated at infinity, and being therefore parallel to cF), we then have the respective angles under which O sees the object in the three states of refraction. The figure shows that the angle is greatest in M ($\angle \alpha N \beta m$), least in H ($\angle \alpha N' \beta h$), and of intermediate size in E ($\angle \alpha N' \beta e$). One sees again that in M this angle increases or diminishes as O is drawn away from or approaches nearer to P. It is the opposite in H. In E the size of the angle remains the same whatever be the distance of O.

If O approaches sufficiently near to P so that its optic centre

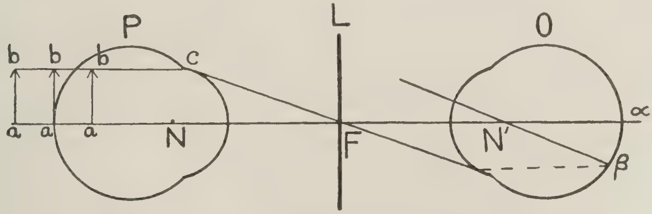


Fig. 119.

coincides with F, ab will be seen under the same angle in the three cases. The magnification then will be the same whether it be M, E, or H. If the optic centre of O were able to be

placed on this side of F, then the angle under which ab is seen would be greatest in H and least in M.

If one place before P the glass which corrects the ametropia of this eye, the value of the magnification will be influenced. If the glass be placed in such a way that its optic centre coincides with the anterior principal focus of P, the magnification will be then the same in M, E, H, and further, it will be independent of the distance of O. (Fig. 119.)

Let L be the correcting lens of P. The rays coming from b will then be in the three cases parallel to the ray cF after their passage through L (for further simplicity in the figure, of rays coming from b, only one is shown); $N'\beta$ is drawn parallel to cF, also β is in the three cases the image of b on the retina.

In reality, while the correcting glass, when it is placed behind the mirror, will always be a little farther from P than F, the magnification will be the greatest in M and the least in H. (*See* below.)

Ophthalmoscopic Field of Vision.—This is the extent of the fundus of the observed eye that can be seen at one moment, and is the accumulation of the various points on the retina that may be seen simultaneously. In measuring the field advantage is taken of a method commonly used in geometric optics, namely, the reversibility of rays.

Now, only those rays from the illuminated part of the observed retina which pass through the pupil of the observer can reach the retina of the observer; consequently, if we can find the area on the retina of the observed eye covered by the image of the pupil of the observer, we are able to delimit the ophthalmoscopic field of vision.

Let A be the observed eye representing hypermetropia, emmetropia and myopia, and B the eye of the observer. Then $a'b'$ will be the image of the pupil ab. This image may be obtained by the use of two rays, one parallel to the optic axis, from each border of the pupil and, therefore, meeting at the retina E, that is, the principal focus of the emmetropic eye, and two other rays which, passing through the nodal point of A, will be unrefracted. By drawing the lines $b'd$ and $a'd'$ and

extending them to *a* and *b*, it will be seen that the field of vision is greatest in hypermetropia, least in myopia, and intermediate in emmetropia.

The size of the image $a'b'$ will be the same as that of the object ab when the two anterior foci FF' of the observed and observer's eye coincide, that is, when ab is distant from A by twice the focal distance of A, as has been seen in considering the images formed by a bi-convex lens. If the distance of ab from A be more than twice the focal distance of A (*i.e.*, more than 30 mm.), then the image $a'b'$ will be correspondingly reduced in size.

The size of the ophthalmoscopic field depends upon :

1. The size of the pupil of the observed eye, hence the advantage of dilating the pupil with a mydriatic.

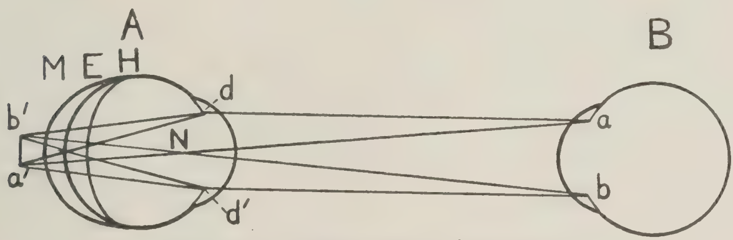


Fig. 120.—Ophthalmoscopic field of vision.

2. The size of the pupil of the observer's eye, or the hole in the ophthalmoscopic mirror, whichever be the smaller.
3. The axial length of the observed eye.
4. The distance between the observed and the observer's eye.

The Field of Illumination.—In ophthalmoscopy two types of mirror are used, the plane and the concave of short focal length.

1. *The Plane Mirror.*—The light is placed near to the side of the observed eye and will form an image in the mirror as far behind the mirror as the light itself is in front. From this image the rays will appear to diverge, and this image is, therefore, called the *immediate source of light*, the term *original source of light* being reserved for the light itself.

The image of L′ will tend to be formed in the neighbourhood

of M, the fundus of the myopic eye, and will actually be formed here when M is the conjugate focus of L′. When this occurs, then the light on M will be a point of light. The field of

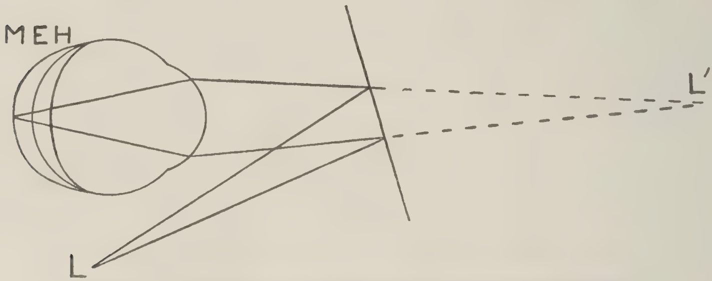


Fig. 121.—The Field of Illumination with the Plane Mirror.

illumination is, therefore, greatest in hypermetropia, least in myopia, and intermediate in emmetropia.

If, however, we withdraw the mirror from the observed eye, then the rays which it reflects will tend to become more and more parallel, in which case both the hypermetropic and myopic fundi will receive rays in the form of a circle of diffusion,

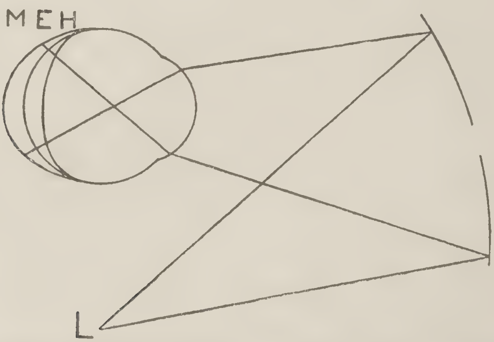


Fig. 122.—The Field of Illumination with the Concave Mirror.

whereas the emmetropic fundus will be illuminated by a point of light.

2. *The Concave Mirror.*—The light is placed near to the observed eye, and a concave mirror is used, of about 20 cm. focal length.

If the lamp coincided with the principal focus of the mirror, then the rays reflected would enter the eye in a parallel direction, and would then be focussed to a point on the retina of the emmetropic eye, the fundus in hypermetropia and myopia being illuminated by circles of diffusion.

The light, however, is always further removed from the mirror, and, consequently, the rays of light reflected into the eye are convergent in direction, and will, by the further refractive power of the observed eye, be made more convergent so as to come to a focus in the vitreous. It will thus be seen that the field of illumination is greatest in myopia, least in hypermetropia, intermediate in emmetropia.

If the light were nearer to the mirror than 20 cm., then the reflected light would be divergent in direction, and the result would be that of a plane mirror, so far as concerns the field of illumination. The same would be the case if the mirror were withdrawn to such a distance that the reflected beam came to a focus between it and the observed eye, and only entered the eye after diverging again from this point.

The Comparative Sizes of the Field of Illumination and the Field of Vision.—In the *direct* method, the field of vision is always smaller than the field of illumination, because the size of the immediate source of light, which largely determines the size of the area of retina illuminated, is always greater than the size of the pupil of the observer's eyes, which determines the area of the field of vision.

The Use of the Ophthalmoscope in the Direct Method.—Ophthalmoscopy is carried out in a perfectly darkened room, for two important reasons: in the dark the pupils dilate and the accommodation is relaxed, and the illumination of the interior of the eye appears very much more bright, owing to contrast with the surrounding darkness.

The source of light must be even throughout in illumination. Nowadays an electric focus lamp is used, but should gas or petroleum be used, a steady uniformly illuminated flame must be obtained. The light given by an Argand gas burner, or a duplex wick petroleum lamp, was much in use before the intro-

duction of electricity, and apart from inconvenience in its use, was most satisfactory.

It is important that the observer should become used to one form of illumination, since with frequent alterations the memory becomes confused as to the appearance of the colour of various conditions of the fundus, more especially of the optic nerve head.

A great improvement has been introduced, whereby the source of light is obscured by an asbestos chimney in the side of which is a circular aperture immediately opposite the brightest part of the flame or filament, and guarded by an iris diaphragm so that illumination may be regulated.

The ophthalmoscope must have a magazine of lenses. It should have four mirrors, two plane and two concave. They are usually arranged in pairs, the small plane and concave being back to back, and the large plane and concave similarly arranged.

The small mirrors are mounted on a turntable inclined at an angle of 45° with the plane of the ophthalmoscope, the concave mirror having a focal length of 20 cm. They are pierced in the middle by a hole of 2 mm. diameter.

The large mirrors are mounted in the plane of the ophthalmoscope, the concave mirror having a focal length of 25 cm., and both being pierced in the middle by a 4mm. hole.

The light is placed by the side of the head of the patient on a level with the top of the ear; the small ophthalmoscope mirror is inclined towards the light and also a little upwards; the observer seats himself by the side of the patient so that the thighs of both are parallel, and with chair of such a height that the eye of the observer is a little above the level of that of the patient.

The right eye is used to examine the right eye of the patient, the left for the left.

A definite method must be followed in all ophthalmoscopic examinations, and good habits in this regard cultivated early.

The cornea, anterior chamber and superficial parts of the lens must be examined with the large concave mirror at

about 33 cm. distance. The fundus is next examined by the indirect method of ophthalmoscopy, this method bearing the same relation to the direct method as does the lower power of the microscope to the higher.

When using the direct method a high power convex lens is turned up behind the sight hole, the ophthalmoscope is held vertically and as near the anterior principal foci of the patient's and observer's eyes as possible; this is a matter of importance if the lenses in the ophthalmoscope are to be used to estimate the error of refraction in the patient's eye. The high-power lens (+ 12) will bring into focus the anterior part of the crystalline lens, and by gradually decreasing its power and bringing up other lenses the whole of the various parts of the media of the eye can be examined under magnification until the level of the retina is reached.

The lens and vitreous are best examined with the plane mirror, and opacities, more especially of the vitreous, may be seen with the plane mirror when nothing is seen if a concave mirror is used. We see opacities in the vitreous mainly by the shadows they cast by intercepting a portion of the rays reflected by the fundus. As these opacities are not completely opaque they allow a considerable part of the light to pass when the retina is brilliantly illuminated, and it is rarely that vitreous opacities are seen by the light they reflect.

The explanation of why the plane mirror reveals fine vitreous opacities which are invisible with a concave mirror is not merely that the light reflected by the concave mirror is too bright, since even if we reduce the brightness of the original source of light we still find that the plane mirror is more suitable. The real explanation is that the plane mirror illuminates a smaller area of the fundus, as may be seen by comparing Figs. 121 and 122. This small area of illumination on the fundus is the source of light when we observe the shadows cast by the opacities in the vitreous, and we may see, by referring to Figs. 1, 2, and 3, that the smaller the source of light used, the more conspicuous the shadow.

When the fundus is being examined the patient should hold

his head erect and fixed in position, and a regular order of observation should be followed.

The patient should be asked to look straight forward into the distance, and the optic disc and large blood vessels examined. With the patient looking into the sight-hole of the mirror the macula should be examined. Finally, the patient should be asked to move the eye in various directions whilst the peripheral portions of the fundus are examined.

If the pupil be not dilated with a mydriatic it may be difficult to examine the macula, owing to the immediate contraction of the pupil, and also the confusing reflexes from the cornea and crystalline lens. It is, therefore, better, after having examined the outer edge of the optic disc, for the observer to incline the face towards the light and so look obliquely through the patient's pupil towards the macula, which is about two disc diameters on the temporal side of the papilla.

Every dioptric system has this property, that the product of the distance of the object from one principal focus and the distance of the image of this object from the other principal focus, is equal to the product of the two focal distances of the system.

$$l'l'' = F'F'',$$

which is Newton's formula. (See p. 53.)

In the eye F' represents the anterior focal distance and F'' the posterior focal distance, l'' the distance between an object situated in the vitreous (g) and the posterior principal focus (f''), l' the distance between g' (the image of g), and the anterior principal focus f'.

Now $$l'' = \frac{F'F''}{l'}$$

$$F' = 15 \text{ mm.}$$

$$F'' = 20 \text{ mm. (in Donders' reduced eye).}$$

Then $$l'' = \frac{300}{l'}$$

Let O be an emmetropic eye, or one rendered so by a suitable

lens. Then the strongest convex lens placed at f' which gives a sharp image of g will have $f'g'$ for its focal length. This focal distance $= l'$. If we divide 300 by this focal distance expressed in millimetres we shall obtain l'' in millimetres.

If P is emmetropic, l'' represents the distance of the object from the fundus of the eye. If P is myopic or hypermetropic, the fundus will be found respectively either behind or in front of the posterior principal focus. The distance of this from the fundus of the eye will have to be added to l'' (or deducted) to find the distance of the fundus from the object in the vitreous.

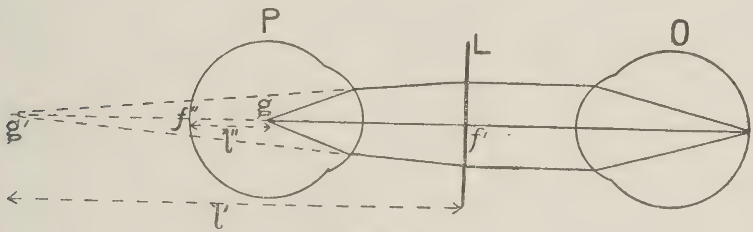


Fig. 123.

Three dioptres of myopia or hypermetropia represents a distance of 1 mm. between the fundus of the eye and f''.

Thus, with a + 10 lens placed before P at the anterior focus of P, a point in the vitreous of P is seen sharply. The focal distance of a + 10 lens is 100 mm.; therefore, $l'' = \frac{300}{100} = 3$ mm.

This is the distance between the fundus and the point in the vitreous when P is emmetropic.

We may judge whether one point of the fundus is situated in front of another by making slight movements of the head with the ophthalmoscope: we shall find that a nearer point moves in the direction of our movement, whereas a point further removed will appear to move in the opposite direction. This is known as parallactic displacement.

The Use of the Direct Method in Measuring Errors of Refraction.—So far in considering the direct method we have supposed the examining eye to be emmetropic and the examined eye either emmetropic, or rendered so by the use of a suitable lens.

If the examined eye be hypermetropic, with its punctum remotum at some point behind it, and the examining eye myopic to such a degree that its punctum remotum coincide with the punctum remotum of the examined hypermetropic eye, then the examining eye can receive a sharp and clear image of the details of the examined eye without the interposition of any glass or the use of the accommodation.

The same will occur when the position is exactly reversed, that is, when the examined eye is myopic and the examining eye is hypermetropic of such an amount that both puncta remota coincide.

It does not follow that the virtual image formed by an observed hypermetropic eye of 4 D will coincide with the image formed by an observing myopic eye of 4 D, or *vice versa*. The image formed by a hypermetropic eye of 4 D is 25 cm. behind its principal point. If a myopic eye be placed in front of such an eye so that the two anterior principal foci coincide, the distance of its punctum remotum, so as to coincide with that of the hypermetropic eye, must be 25 cm. plus the distance between the two eyes, namely 30 mm., the sum of the anterior focal distances of the two eyes. The amount of myopia must, therefore, be about 3·5 D.

Again, if we take a myopic eye of 4 D and place in front of it a hypermetropic eye so that the two anterior principal foci coincide, then, in order that the puncta remota may coincide, this hypermetropic eye must have its punctum remotum at a distance of 25 cm. less the distance between the two eyes, namely, the sum of their anterior focal distances; that is, its punctum remotum must be at 22 cm., which means a hypermetropia of about 4·5 D.

A further error arises, since the anterior foci of the two eyes never coincide, and they are, therefore, an unknown distance apart, as it is impossible to bring the two eyes so close.

Now, theoretically, we should be able to measure ametropia by the use of lenses in the sight hole of the ophthalmoscope when the anterior foci of the two eyes and the optical centre of the lens coincide. If, however, we concluded that the number

on the lens measured the ametropia we should commit an error, since for this to be the case it would be necessary for the lens to be in contact with the cornea of the examined eye, and for the principal focus of the lens and the punctum remotum of the eye to coincide.

Thus, in myopia, the correcting lens is nearer the punctum remotum of the eye than the eye itself, and hence has a focal length that is too short by the distance between the eye and the optic centre of the lens. Hence the reading is always too high.

In hypermetropia, on the other hand, the lens is farther from the punctum remotum of the eye than the eye itself, and hence the reading is always too low.

Apart from this, for readings to be of value the accommodation of both the observed eye and that of the observer must be relaxed, and any deviation from this not only causes an error in the reading of the lens that should correspond with the error of refraction, but should either eye accommodate, the anterior principal foci are further separated and a still greater error is introduced.

An astigmatic eye, the common example of curvature ametropia, has two anterior foci, and, consequently, is unable to see sharply any object in the exterior world. The image of a point formed upon the fundus will never be a point, but either a line or a circle of diffusion. For this reason a point upon the fundus of an astigmatic eye cannot be seen sharply by ophthalmoscopic examination, unless a cylindrical lens in an appropriate meridian can be interposed between the observer and the observed eye. As has been pointed out, the principal meridians in astigmatism are at right angles one to the other, and are usually placed so that the meridian of less refraction is horizontal and the other vertical.

Take an astigmatic eye, emmetropic in the horizontal meridian and myopic in the vertical, and let the observer be emmetropic. The rays leaving the observed eye in the horizontal meridian are parallel, and, consequently, will come to a focus upon the fundus of the observer. The rays leaving the eye in the vertical meridian are convergent, and so will have

come to a focus before the fundus of the observer is reached. The result will be that each point on the fundus of the observed eye will be focussed upon the fundus of the observer as a vertical line, and so the observer will be able to see sharply all parts of the object on the fundus of the observed eye in the vertical meridian, whereas all parts more horizontal will appear diffuse.

If now a concave spherical lens be placed in the sight hole of the ophthalmoscope until the horizontal meridian is rendered emmetropic, then points on an object on the fundus of the observed eye will be sharply focussed in the horizontal meridian, those in the vertical being now indistinct.

In the application of the direct method of ophthalmoscopy to

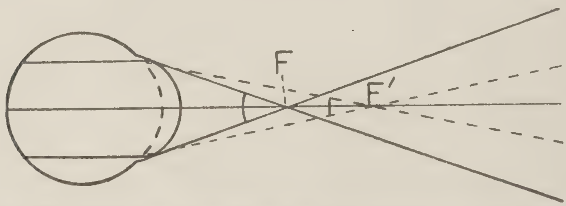


FIG. 124.—To show that in astigmatism the Fundus in the two Principal Meridians is seen under Different Angles and, therefore, Different Magnification.

the correction of refractive errors a search must be made as near to the macula as possible for small branches of blood-vessels that run in the principal meridians of the astigmatic eye. These are successively brought to a sharp focus by a suitable spherical lens, and so the refraction in the two meridians is estimated. The correcting lens is the strongest convex, or the weakest concave with which the vessel in each meridian is seen sharply.

In astigmatism the magnification of objects upon the fundus, as seen by the observer, is different in the two meridians of greatest and least refraction. Owing to the fact that there are two anterior foci in curvature ametropia, the visual angle under which the observer will see the details of the fundus of the observed eye will vary in different meridians. Parallel rays

leaving the fundus in the meridian of greater refraction will pass through the anterior focus F, and those leaving the fundus in the meridian of less refraction will pass through F′ at a greater distance from the eye than F. Consequently the observing eye will see the rays passing through F under a greater angle than those passing through F′. Therefore, in curvature ametropia the magnification will be greatest in the meridian of greatest refraction and least in that of least refraction, so that we may compare the effect to that produced by looking at an object through a magnifying glass more powerful in one meridian than another. The result is that in regular astigmatism with the rule, the optic nerve head appears

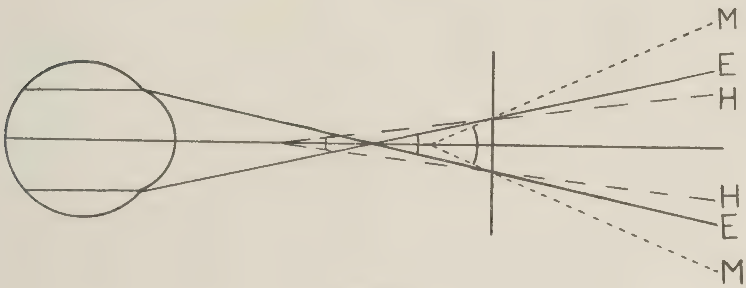


Fig. 125.

elongated and oval in outline with the major axis in the meridian of greatest refraction.

In axial ametropia, if the correcting lens is placed so that its optic centre coincides with the anterior principal focus of the eye, there will be no alteration of the visual angle under which the observer views the details of the fundus of the observed eye. Now it is very difficult, almost impossible, to bring the correcting lens to the anterior focus of the eye under examination, and in almost all cases the lens is more or less farther distant from the eye. The result will be that the concave glass which corrects the myopia will cause the rays to diverge more than in emmetropia, and the convex lens which corrects the hypermetropia will cause the rays to diverge less : thus the visual angle in such circumstances is greatest in myopia, least

in hypermetropia, as compared with the condition of emmetropia. The magnification will, therefore, usually be greatest in myopia, intermediate in emmetropia, and least in hypermetropia.

In very high degrees of myopia considerable difficulty is experienced in direct examination, owing to the impossibility of placing the correcting lens at the anterior principal focus of the eye. The result is that a much higher concave lens than that which will correct the myopia must be used to overcome

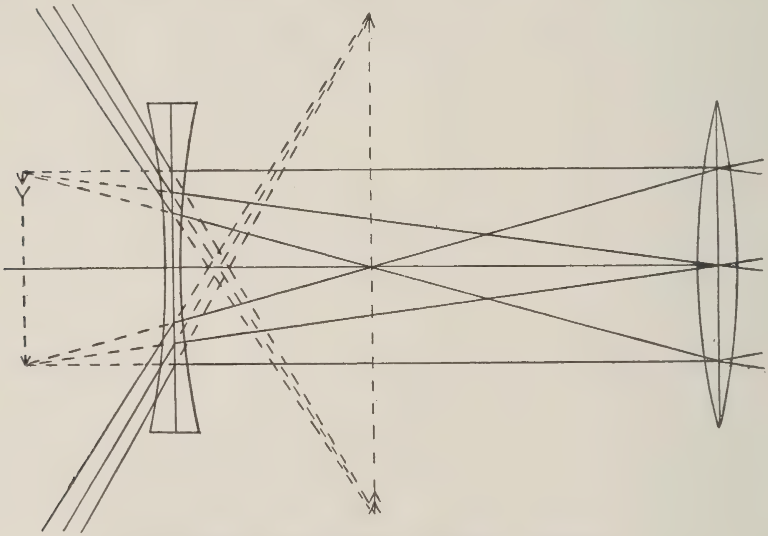


Fig. 126.—Path of Rays in a Galilean Telescope.

the excessive convergence of the rays as they leave the eye, and also an enormous magnification.

The diagram will show that the condition produced is that of a Galilean telescope, the dioptric apparatus of the eye corresponding to the objective, and the ophthalmoscope glass to the eyepiece. The rays converging to the virtual image of the fundus of the eye under examination are rendered approximately parallel, and so the visual angle under which they are seen is much increased, the observer projecting the rays to his minimal point of distinct vision.

In high hypermetropia the difficulty is less, but the magnification of the retina is very much reduced owing to the great reduction of the visual angle under which the details of the fundus are seen. The condition produced is that of viewing an object through the wrong end of a Galilean telescope, the eyepiece representing the dioptric apparatus of the eye under examination and the lens in the ophthalmoscope the objective.

The Indirect Method, or Examination of the Inverted Image of the Fundus

If the fundus of a myopic eye be illuminated, rays of light will emerge from the eye so that an inverted real image of the

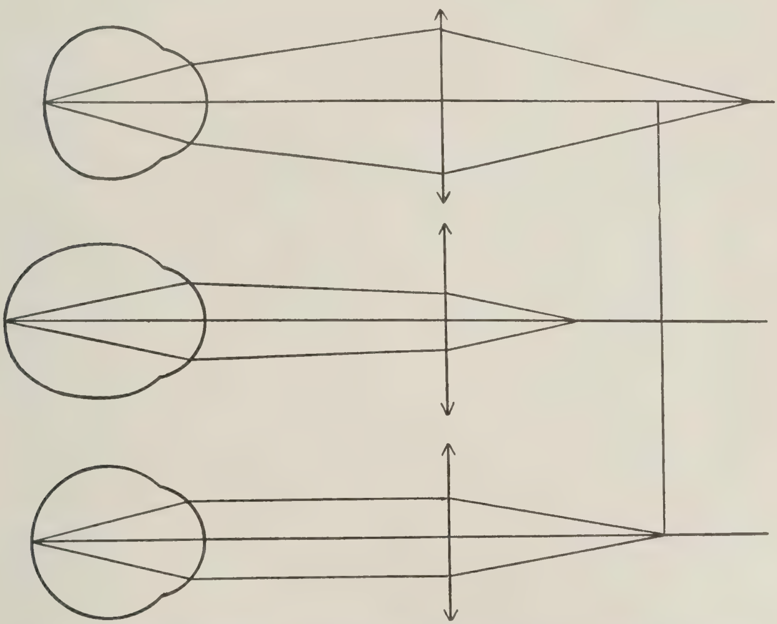


Fig. 127.—The position of the Inverted Image of the Fundus in Hypermetropia, Myopia and Emmetropia.

fundus will be formed in front of the eye, and if this image be in a suitable situation the observer will be able to focus this image upon his retina by an effort of accommodation.

In the case of an emmetropic or hypermetropic eye it is possible to render such an eye artificially myopic by placing in front of it a convex lens of suitable strength, and in this way cause an inverted and real image of the fundus to be formed in front of the eye.

This image, if formed at a suitable place, will be focussed upon the retina of the observer if he accommodate. The effect of the convex lens will be to form an image of the fundus of an emmetropic eye at the principal focus of the lens ; in the case of the hypermetropic eye it will be further from the lens than its principal focus, and in the case of the myopic eye at a distance less than its principal focus.

In Emmetropia.—So as to simplify the diagram, let the lens *PQ* be placed in front of the eye so that its principal focus coincides with the nodal point of the eye, and let their optic axes coincide.

Let A be an emmetropic eye, *ab* a portion of the fundus of which the point *a* lies on the optic axis.

The rays emergent from the eye are parallel in direction, and

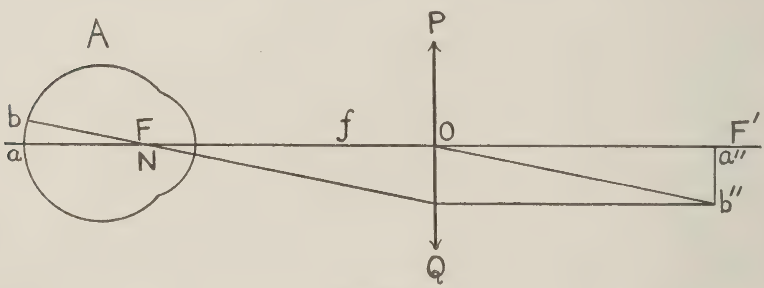


Fig. 128.

so there will be formed behind the eye an image $a'b'$ at infinity, which is the virtual image of *ab*.

This image will be the object so far as the lens *PQ* is concerned.

The ray $b'N$, passing through F the principal focus of the lens *PQ*, will, after refraction, be parallel to the axis of the lens. In its course the image of b' will be found.

The ray $b'O$, parallel to bN, undergoes no refraction by *PQ*

as it passes through the optic centre O. Along it also will be found the image of b'. The image is therefore at b''.

Draw $a''b''$ at right angles to the optic axis, and since $a'b'$ is also at right angles to the optic axis, $a''b''$ will be the image of $a'b'$ and, therefore, of ab, formed at the principal focus of the lens PQ.

In Hypermetropia.—As explained when considering the

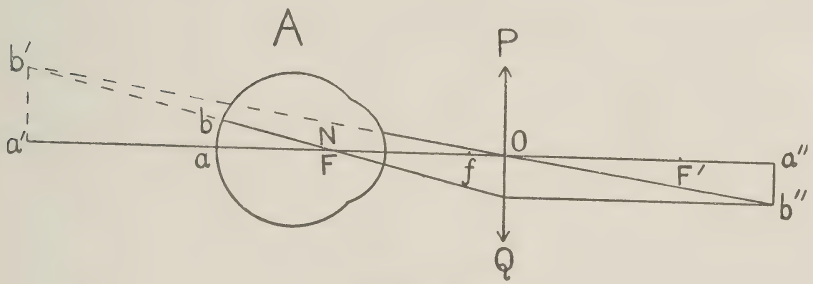


FIG. 129.

direct method of ophthalmoscopy, rays emitted from a hypermetropic eye are divergent in direction, in such a way that the object ab on the retina of the eye A gives rise to a virtual erect image at $a'b'$ at a point behind the eye between its principal focus and infinity. This image $a'b'$ will be the object from which rays proceed when considering the image of ab formed by the lens PQ, which is placed in relation to A as when considering emmetropia.

Choosing similar rays, $b'N$ and $b'O$ as above, an image will be formed at $a''b''$ farther from the lens than its principal focus.

In Myopia.—Let A be a myopic eye and ab a portion of the fundus. Rays leaving A are convergent in direction so that the object ab on its retina gives rise to a real inverted image at $a'b'$. This image will be the virtual object for the lens PQ placed between it and the eye. Choosing the same rays as in the two previous cases, Ob' passing through the optic centre of the lens PQ will be unrefracted, and Nb' passing through F, the principal focus of the lens, will take a course parallel to the optic axis. The point of intersection of these rays

b'', will be the image of b on the retina of A, and $a''b''$ at right angles to the axis will be the image of $a'b'$, and therefore of ab formed at a point between the lens PQ and its principal focus F'.

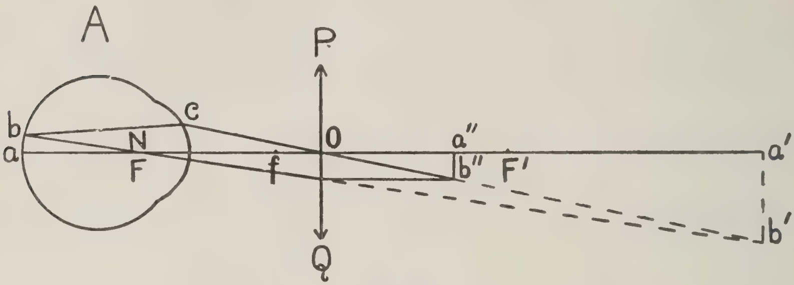


Fig. 130.

The Magnification of the Inverted Image.—The image formed in indirect ophthalmoscopy is larger than the object, *i.e.*, that portion of the retina giving rise to the image ; and this

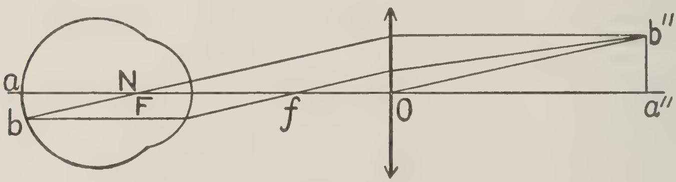


Fig. 131.

enlargement is the proportion that the object ab bears to the image $a''b''$.

$$\text{The Magnification} = \frac{a''b''}{ab}$$

The triangles aNb, $a''Ob''$, are similar, the side ab is parallel to the side $a''b''$, and the side bF is parallel to the side Ob'', and, consequently :

$$\frac{a''b''}{ab} = \frac{a''O}{aN}$$

and thus $$M = \frac{a''O}{aN}$$

This equation will vary with the dioptric value of the lens held between the two eyes.

We know the value of aN in the reduced eye, *i.e.*, 15 mm., and if we know the dioptric value of the lens we know also the value of $a''O$, because it is equal to the focal length of the lens. The strength of the lens commonly used is 13 D, and it has, therefore, a focal length of 75 mm., and so in this case the magnification is :

$$M = \frac{75}{15} = 5.$$

If, however, we use a lens of less dioptric value, the magnification will be greater, but in such a case the image is projected to a point so near to the observer's eye that he is unable to accommodate for it.

When the lens is held so that its principal focus coincides with the nodal point of the eye, it is easy to see that the magnification produced is influenced by the axial length of the eye.

In axial myopia, the line aN is increased, and, consequently, the value of the fraction $\frac{a''O}{aN}$ is reduced, that is, the magnification is less, whereas in axial hypermetropia, the value of aN is reduced, the fraction $\frac{a''O}{aN}$ is increased, and so also the magnification.

There is yet another factor which influences the magnification, and that is the position of the lens in relation to the anterior principal focus of the eye under examination, but this alteration in magnification is only effected in eyes whose refraction is other than emmetropic.

In *emmetropia* the size of the inverted image does not vary with the position of the lens.

The rays proceeding from an emmetropic eye are parallel in direction ; consequently, wherever the lens may be placed, the rays are parallel, and are always brought together at the principal focus of the lens ; the result is that the angle formed by the rays bN and aN at the nodal point of the eye is always

equal to the angle $a''Ob''$ formed at the optic centre of the lens; the result is that $a''b''$ is a constant, and the relation in size between $a''b''$ and ab is always the same.

(*a*) *When the principal focus of the lens coincides with the anterior principal focus of the eye.*

In this case the size of the image is the same in emmetropia, hypermetropia and myopia.

Taking any ray Mi parallel to the optic axis and projected from the retina MEH, it passes through the anterior focus of the eye, and also through the principal focus of the lens; this ray, therefore, after refraction by the lens, is parallel to the optic axis of the lens. If now we take a ray which passes through the nodal point of the eye, in the case of emmetropia

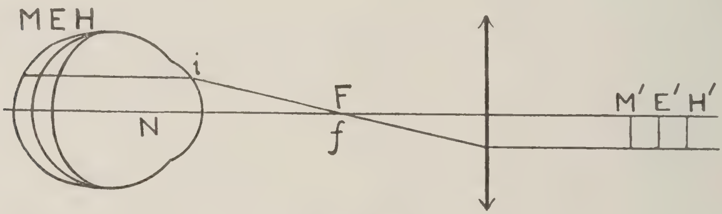


FIG. 132.

it leaves the eye parallel to the previous emergent ray, and so the image of the area on the fundus of the emmetropic eye is formed at the principal focus of the lens (p. 174).

In hypermetropia the ray passing through the nodal point leaves the eye in a direction divergent to that of the ray iF, and so the image of the area on the fundus of the hypermetropic eye is formed at a point farther removed from the lens than its principal focus.

In the myopic eye, the ray passing through the nodal point leaves the eye convergent to the ray iF, and so the image of the area on the fundus of the myopic eye is formed nearer to the lens than its principal focus. As, however, the delimiting ray is parallel to the optic axis, the images in emmetropia, hypermetropia and myopia are of the same size.

(*b*) *When the principal focus of the lens is nearer to the eye than its anterior principal focus.*

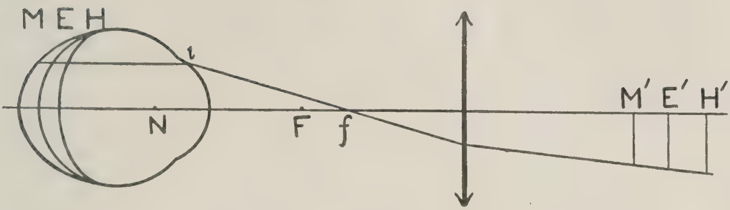


FIG. 133.

The ray parallel to the optic axis still passes through the anterior focus of the eye, but since the anterior focus is nearer to the lens than its principal focus, the ray leaves the lens in a direction divergent to the optic axis. If now we draw a second ray from the fundus of each eye through the nodal point *N*, we know that this is parallel in direction to the previous ray if the eye be emmetropic, and that an image is formed at the principal focus of the lens, and of constant size, whatever be the position of the lens in relation to the anterior focus of the eye.

In hypermetropia the second ray *HN* is divergent in direction to that of the ray *if*, and since the image of *H* is formed farther from the lens than its principal focus, the image is increased in size as compared with the constant size of the image in emmetropia.

In myopia, owing to the rays *if* and *MN* being convergent, an image of the area of the retina is formed nearer to the lens than its principal focus, and, consequently, smaller in size than that formed in emmetropia, which is constant, and still smaller than the image formed in hypermetropia.

(*c*) *When the principal focus of the lens is farther from the eye than its anterior principal focus.*

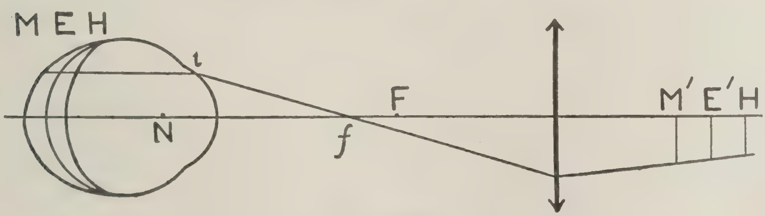


FIG. 134.

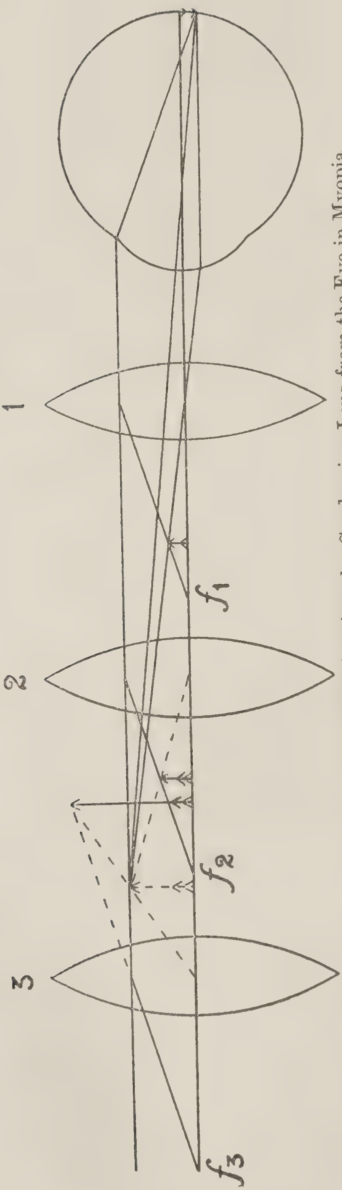


FIG. 135.—To show the Result of Withdrawing the Condensing Lens from the Eye in Myopia.

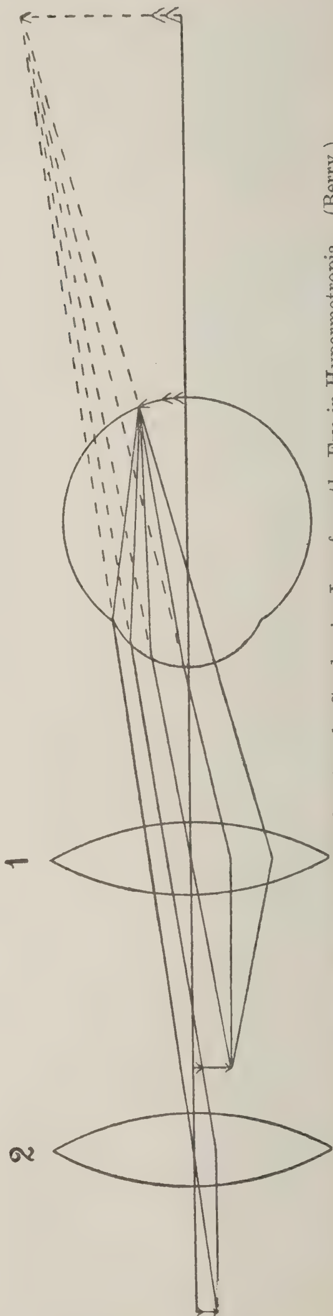


FIG. 136.—To show the Result of Withdrawing the Condensing Lens from the Eye in Hypermetropia. (Berry.)

Again the ray parallel to the optic axis of the eye passes through the anterior principal focus, but since the distance of this point from the lens is greater than the focal length of the lens, after refraction, it converges towards the optic axis. If second rays be drawn from the retinæ *MEH* it is seen from our previous considerations that the images are formed at *M'E'H'*, showing that the image in myopia has the greatest magnification, that in hypermetropia the least, whereas the size in emmetropia, being constant, takes an intermediate position.

The practical result of these considerations is this, that if the position of the lens relative to the anterior principal focus of the eye be varied, in emmetropia the size of the image on the retina will remain constant, but in hypermetropia the image will increase as the lens is approximated to the eye, and decrease as the lens is withdrawn, whereas in myopia the size of the image will decrease as the lens is moved nearer to the eye, and increase as the lens is withdrawn.

We have, theoretically, a means of estimating an error of refraction, for by placing a lens before the eye so that on moving the condensing lens the size of the image remains constant, we know the lens that renders the eye emmetropic. The method has no practical application, since in the low degrees of ametropia the variations in size of the image of the fundus on moving the condensing lens are so small that they are not appreciated by the observer.

In Astigmatism.—Astigmatism is a curvature ametropia. An eye the subject of astigmatism has, therefore, two anterior focal points, the one corresponding to the meridian of greater curvature nearer to the eye than that corresponding to the lesser curvature, and the lens cannot be held at the same moment at both anterior foci. The result of this is that there is produced an unequal magnification of the fundus in the two principal meridians, and a round structure such as the optic disc has an oval outline, the lengthening of the oval taking place in the myopic meridian when the lens is drawn from the eye, and in the hypermetropic meridian when the lens approaches the eye.

The Field of Illumination.—In the indirect method the light is placed near to the eye to be examined, and the mirror is held at such a distance that the reflected beam comes to a focus at a short distance in front of it and diverges again before reaching the eye. The lens held between the mirror and the eye, however, renders these rays convergent, so that they meet the cornea as a convergent beam. Then, being rendered still more convergent by the refractive apparatus of the eye, they are brought to a focus in the vitreous, so that the field of illumination is greatest in myopia, least in hypermetropia, and intermediate in emmetropia (*cf*. Fig. 122).

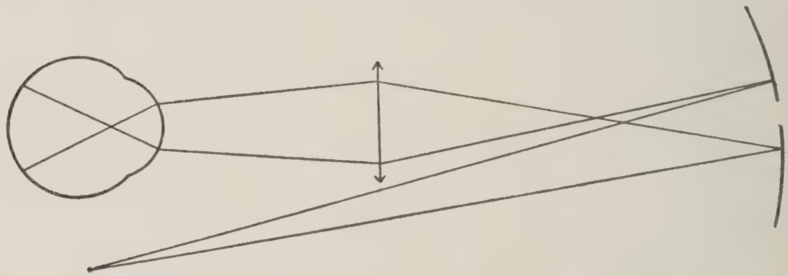


FIG. 137.—Field of Illumination in Indirect Ophthalmoscopy.

The Ophthalmoscopic Field of Vision.—In the indirect method the size of the pupil of P does not affect the size of the ophthalmoscopic field, provided it is larger than the image of the pupil of the eye O, which is formed by the condensing lens in the pupil of the observed eye. As will be seen in the figure, the size of the area $b'c'$ on the retina of P will depend upon the size and power of the lens used, provided one places the lens in such a way that the image of the pupil of O coincides with the centre of the pupillary opening of P.

The size of the condensing lens is regulated by the spherical aberration seen with a lens of large diameter, so that in spite of the larger field obtained by lenses of a greater size, a lens of $2\frac{1}{2}$ inches in diameter is the largest that can be used with profit.

In the figure let the condensing lens AB be held so that its principal focus coincides with the pupil of P and thus the point

where $c'b'$, the image of the pupil bc, falls. The limits of the field of vision are cut off by the lines $c'c'$ and $b'b'$.

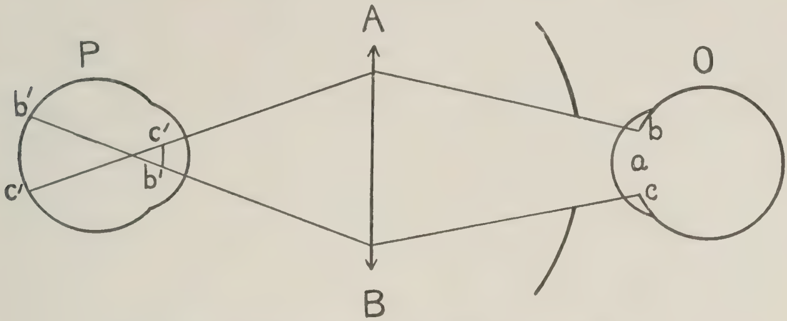


Fig. 138.—Field of Vision in Indirect Ophthalmoscopy.

The Comparative Sizes of the Field of Illumination and Field of Vision.—In the *indirect* method the field of illumination is smaller than the ophthalmoscopic field, since, with the apparatus usually employed, the rays of light from the immediate source of light are brought to a focus by the condensing lens farther back in the vitreous than is the image of the pupil of the observer formed by the condensing lens (usually in the plane of the pupil of the observed eye). It is when the lens is held in this way that the ophthalmoscopic field is greatest.

The field of illumination can be increased by using a plane mirror, but the illumination is thereby very much diminished.

The Method of Examination by the Indirect Method.—As in the direct method, the examination must be carried out, if the best results are desired, in a room from which all outside light is removed, that is, in a room in which the only source of light is that to be used in the examination. It has the advantage that the illuminated portion of the retina is by contrast with the surrounding darkness more clearly seen, and the examination is made more easy by the greater dilatation of the pupils of the patient and his relaxation of accommodation. We use a concave mirror with a focal length of 25 cm., the central hole of which has a diameter of 3 mm. It is an advantage to be able to place in the sight hole lenses of different dioptric values,

and most ophthalmoscopes with a battery of lenses are provided with a large concave mirror suitable for indirect examination.

The condensing lens, which should be fairly large, but not of greater diameter than 7 cm., has a dioptric value of 13 D, and consequently its focal length is 7·5 cm. This is the most useful strength, although, as has been explained elsewhere, a lens of higher dioptric value is more useful when the examined eye has a high degree of hypermetropia, such as is seen in aphakia, and one of lower dioptric value in high degrees of myopia.

The source of light, as in the direct method, should be small and bright, and there is a great advantage in having it surrounded by an asbestos casing in the side of which is a hole 2 cm. in diameter, guarded by an iris diaphragm. The light should be moveable, both up and down and from side to side.

The source of light may be placed above and behind the patient's head, or more conveniently by the side of the head on the side of the eye to be examined, and on a level with the ear. If the light has a casing it may be placed in advance of the patient's face, which has the advantage that then the patient's eye is in complete darkness.

The surgeon sits in front of the patient with the mirror, and with the hole in the shade of the light directed towards him. As in the direct method, the surgeon should be able to use either eye equally well, and, as we shall explain, use his right eye when examining the right eye of the patient, and so on.

The surgeon should so arrange his position that his own eye is directly opposite the eye of the patient he wishes to examine—for instance, suppose it is desired to examine the right eye of the patient, the surgeon must sit so that his own right eye is opposite that of the patient. He then shines a light with the mirror into the patient's eye, the pupil of which is immediately filled with a red glow ; if now the condensing lens be held in front of the eye details of the retina will be observed. As the inverted image of the fundus is formed near the principal focus of the lens, and this point may be inconveniently near the surgeon so that he has to use a great amount of accommodation to see it, or unduly retract his head, some assistance will be

gained if a plus 2 D spherical lens be moved into the sight hole of the mirror. It will depend upon the direction of the visual axis of the patient what portion of his retina will come into view, and the means whereby various portions may be examined will be explained a little later on.

There is one great difficulty that baulks all beginners, and is often of considerable annoyance to the experienced practitioner, and that is the presence of three very bright images of the ophthalmoscopic mirror. The anterior surface of the lens is a convex mirror in which will be formed a virtual image of the mirror situated behind the lens ; the posterior surface of the lens viewed from in front is a concave mirror, which will form a smaller real inverted image of the mirror in front of the lens. The third image is that formed by reflexion in the anterior surface of the cornea, itself a convex mirror ; this image is situated roughly 4 mm. behind the cornea, and is virtual and erect.

The two troublesome reflexions in the lens can be easily avoided by tilting the condensing lens. One image being erect and virtual and the other inverted and real, they will move in opposite directions, and so in this way a clear space between the two can be found through which the fundus of the eye can be examined unimpeded so far as the images in the lens are concerned. No amount of tilting of the lens will affect the corneal image, and the method of avoiding this will be described in dealing with the examination of the macula.

To examine any particular chosen part of the retina it is necessary that the eye of the patient be moved in such a way that this portion of the retina comes opposite the pupil, and so falls upon the visual axis of the observer. If it is desired to examine the internal part of the retina the eye must look inwards ; if the outer part, outwards ; if the lower part, downwards ; and if the upper part, upwards—that is, the eye must be moved in the direction in which the portion of the retina to be examined lies.

There are two portions of the fundus that merit special attention, and special manœuvres are necessary to bring them

into a suitable position for examination; these are the papilla and macula lutea.

Supposing that the right eye is being examined and the examiner's right eye is directly opposite it, the patient should be requested to look inwards towards his nose, and it is found that a convenient object of regard is the top of the observer's right ear. In this way the papilla will lie upon the observer's visual axis. With the patient's left eye immediately in front of the surgeon's left eye, the papilla will come into view when the patient observes the surgeon's left ear.

To examine the macula it is necessary that the visual axes of the patient and observer should coincide, that is, that the patient should look to the middle point of the mirror. This will cause immediate and extreme contraction of the pupil, and this small pupil will be largely occupied by the bright image of the mirror found in the cornea. The result is that no details of the macula are seen unless the pupil be dilated with some suitable mydriatic such as homatropine.

We have seen above how the images of the mirror formed in the lens can be avoided, and also that no tilting of the lens has any effect upon that formed in the cornea. Now the lens forms a real inverted image of the fundus near its principal focus on the side of the lens next to the observer, so that if the lens be moved upwards, the image of the fundus moves in the same direction. Keeping the mirror fixed, the image in the cornea does not move, and in this way the image of a point on the fundus may be moved to one side of the image of the mirror in the cornea, and its obstructive qualities overcome.

The image, being formed near the principal focus of the lens, moves much more rapidly than the movement of the lens; and it should be remembered that as the image moves in the same direction as the lens, the point on the fundus which forms the object must necessarily move in the opposite direction. If now the lens be kept steady, and the observer's head be moved, then the image will be displaced in the opposite direction to that of the head, so that if the head move to the right the image will be displaced to the left.

These two manœuvres may be used to examine the macula, to avoid the direct fixation of the centre of the mirror by the patient and the consequent extreme contraction of the pupil.

Let the patient fix the top of the surgeon's ear so as to bring the papilla opposite the pupil. It must be remembered that the image of the macula is to the nasal side of that of the disc in

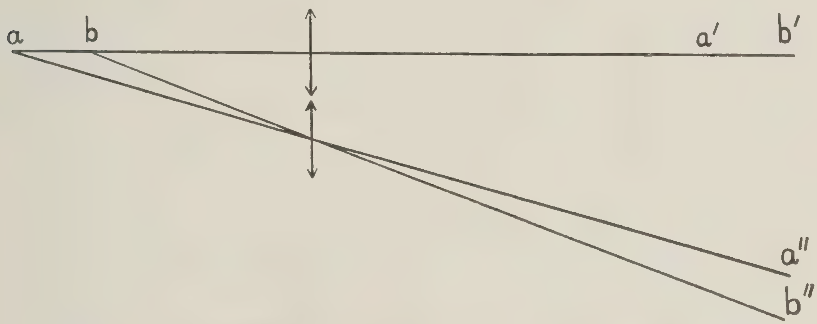


FIG. 139.—To show Parallactic Displacement in the Indirect Method of Opthalmoscopy.

the indirect method, so that the head of the surgeon must be moved to the temporal side of the patient to obtain a view of his macula.

This method of examining the different parts of the fundus is similar to that whereby we distinguish differences of level of the fundus. The phenomenon is that of *parallactic displacement*. If we have two points a and b on different levels, as the condensing lens is moved the point nearer the observer will move at a greater rate than the one on a deeper level, and the images a' and b' will move to a'' and b''.

However, an examination of the macula without dilatation of the pupil is very imperfect and unsatisfactory.

Preliminary Examination at the Distance of One Metre.—This is usually carried out with the large plane mirror and will give information mainly concerning the refraction of the eye. This will be explained fully in the section dealing with retinoscopy.

Owing to the divergence of the rays leaving the *hypermetropic* eye, we are able, by an effort of accommodation, to see some details of the fundus of such an eye, and since these rays are projected to the punctum remotum of the eye, the image is erect and virtual ; and will appear to move in the same direction as the observer's head.

In *myopia*, fundus details may also be seen, owing to the formation of a real inverted image of the fundus at the punctum remotum of the eye which lies between the eye of the patient and that of the observer. For this point the observer accommodates and the image will appear to move in the opposite direction to that of the head of the observer.

In *emmetropia*, *low hypermetropia* and *low myopia*, the rays leaving the eye are approximately parallel in direction, the result being that the observer is only able to obtain a clear image of a very small portion of the retina, and that only when his accommodation is completely relaxed and so focussed for parallel rays.

During examination by this method the observer accommodates for the reflex in the pupil of the observer ; he is thus unable to bring to a focus any but divergent rays.

The Distant Direct Method at 33 cm. — Provided the observer is emmetropic, or rendered emmetropic by a suitable lens and able to accommodate for a distance of 33 cm., much useful information is obtained by the use of the large concave mirror at this distance. The main use of the method is :

(*a*) to study the *transparency of the refractive media*, and

(*b*) to *detect detachment of the retina* or some growth or foreign body in the vitreous.

The Transparency of the Refractive Media.—Light is reflected into the eye by the large concave mirror and the observer sees the pupil filled with a uniform red glow, but if there are any opacities in the transparent media they will appear as black spots upon a red background. All opacities, unless very gross (such as a large clot of blood in the vitreous), appear black because seen by the light which they cut off as it is reflected

from the fundus of the eye. It may be that when light is reflected into the eye the pupil appears quite black, as when the lens is opaque or the vitreous full of blood.

We are able not only to see opacities in the media, but also to diagnose in what medium they may be and at what depth: moveable opacities must necessarily lie in either the aqueous or vitreous, and by causing the patient to move his eye in various directions we are able to see the opacities floating about. If the opacity is in the aqueous, we diagnose its position by focal illumination, otherwise it must be in the vitreous, which is not of the usual viscous consistency but has become fluid by disease.

If the opacity is fixed, and does not move spontaneously, it is in either the cornea, lens or vitreous, which in that case is healthy and of its usual consistency.

To determine the exact position of an opacity, we make use of the *parallactic displacement* of the opacity in relation either to the margin of the pupil or, as we shall see later, to the *corneal reflex*.

Let the observer's eye be at A, and let there be four opacities in the eye B along the optic axis, the opacity 4 coinciding with the centre of rotation of the eye. The observer will see these four opacities as one, in the centre of the pupil of B. These

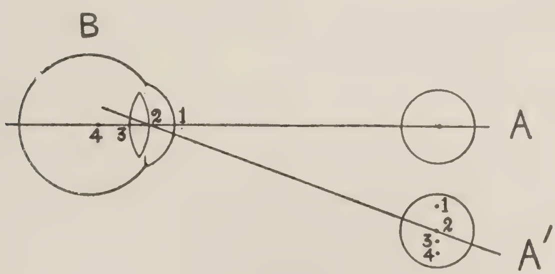


FIG. 140.

opacities, however, are so arranged that 1 is in the cornea, 2 in the anterior capsule of the lens, and 3 in the posterior capsule. If now the observer move downwards into position A′, or, what comes to the same thing, the patient look upwards, the positions

of the opacities relative to the edge of the pupil will be changed. The opacity 2 will retain its relation to the edge of the pupil unchanged, 1 will travel in a direction opposite to that of the observer's eye towards the upper margin of the pupil, whereas 3 and 4 will move downwards towards the lower margin of the pupil. We thus see that with a small excursion of the eye, opacities in the plane of the pupil will appear to remain stationary; those in front of this plane will move in the same direction as the eye, whereas those behind the plane of the iris will appear to move in the opposite direction, the more rapidly the farther back in the eye the opacity may be.

The other point of reference in deciding the position of an opacity is the *corneal reflex*, which is the image of the mirror of the ophthalmoscope. Since the radius of curvature of the cornea is 8 mm., the reflected image of the mirror formed in the cornea when used at 33 cm. is approximately 4 mm. behind it, just behind the anterior surface of the lens. The centre of curvature of the cornea is about 1 mm. behind opacity 3 in the diagram, so that any opacity in the posterior part of the lens is always covered by the corneal reflex in any position of the eye.

Opacities in front of the centre of curvature move in the same direction with regard to the reflex, and opacities behind it move in the opposite direction to the movement of the eye.

Detachment of the Retina.—In detachment of the retina the colour of the reflex will be altered over the area of detachment, usually appearing less red, or even grey. Also, owing to the forward displacement of the retina, the eye has become hypermetropic over this area, and we may be able to recognise individual blood vessels.

The Illumination of the Fundus.—If we take a bundle of parallel rays reflected from a small area of a distant evenly illuminated surface, all sections have the same intensity of illumination, and equal parts of different sections are equally luminous, because all sections are equal.

Taking a converging bundle of rays, the sum of light is still

the same in all sections, but equal parts of different sections have a different intensity of illumination, which varies inversely as the square of the distance from the summit of the cone of luminous rays—that is, the nearer the section to the summit the greater the intensity of illumination.

The amount of light falling upon the fundus depends, on the one hand, upon the luminosity of the source of light, and the completeness with which the mirror reflects the light, and on the other upon the quantity of light that penetrates into the eye, that is, upon the size of the pupil and the extent to which it is occupied by the rays reflected by the mirror.

The cornea and anterior chamber act as a convex lens, consequently rays of light are rendered more convergent, so that more luminous rays enter the pupil than if there were no anterior chamber, and one may imagine a pupil of greater diameter situated upon the anterior surface of the cornea.

If an *emmetropic* eye, with accommodation at rest, receives a bundle of *parallel rays*, there will be a cone of luminous rays with the base at the pupil and the apex upon the retina. This spot, the retinal image of the source, will have the same amount of light falling upon it as the whole pupil surface. Thus with a plane mirror reflecting the parallel rays from the sun, if its area be S, and the amount of light reflected be I, and the pupil surface p, the amount of light entering the eye is to that reflected by the mirror as $p : S$, and, therefore, the amount of light (i) entering the eye is

$$i = I \frac{p}{S}$$

In the case of a *hypermetropic eye*, a similar cone of luminous rays is formed, but as the retina is nearer to the cornea than the apex of the cone, there is produced a section of the cone the total brightness of which is equal to that of the pupil surface or of the apex of the cone, since we have upon the retina the same quantity of light, but spread over a greater surface than in emmetropia. The intensity of illumination at any point upon this surface is, however, less than is the case in the emmetropic eye.

In *myopia* the result is the same. The rays meet nearer to the cornea than the situation of the retina, consequently here is formed a circle of diffusion as in hypermetropia.

When *divergent rays* fall upon an *emmetropic eye*, these rays are rendered less divergent, so that we have a cone of luminous rays in which the apex is in front of the eye, with one section at the pupil and another upon the retina.

The amount of light (i) entering the pupil will be :

$$i = I \frac{p}{4\pi d^2}$$

where I is the amount of light at the source, p the pupil area, and d the distance of the source from the pupil. The retina receives the same amount of light as the pupil, but each point of the retina is more or less bright than the surface p, according as the area of the retina illuminated is smaller or larger than p. When divergent rays fall upon an *emmetropic* eye they are rendered less divergent. Rays coming from a point within the anterior principal focus will still be divergent, so that we have a cone of luminous rays in which the apex is in front of the eye, with one section at the pupil and a still larger section upon the retina. If, however, the rays come from a point beyond the anterior principal focus, they will be rendered convergent, so that we have a cone of luminous rays with its apex behind the eye and the base at the pupil.

If the eye be *hypermetropic*, the rays received by the retina are still less convergent than in emmetropia, consequently the rays that pass through the pupil are spread over a still greater retinal area, so that each point on the retina is less illuminated than in emmetropia.

In *myopia*, if the *divergent rays* proceed from the punctum remotum of the eye, then they are brought to a focus upon the retina and there are two cones of luminous rays with a common base, the pupil ; the apex of one cone is the source of light, the apex of the other, the image on the retina.

The amount of light entering the pupil is still represented by the equation

$$i = I \frac{p}{4\pi d^2},$$

and the retinal area illuminated is much smaller, but more brilliant than in the previous case.

From the above formula, and supposing the source of light to coincide with the punctum remotum of the myopic eye, it follows that the image formed upon the retina will be the brighter the nearer the punctum remotum to the eye, that is, the higher the myopia.

If, however, the source of light is nearer to the myopic eye than its punctum remotum, the rays are no longer focussed upon the retina, so that we have the same condition as in emmetropia.

In the same way, if the source of light be beyond the punctum remotum of the myopic eye, the rays will have come to a focus in front of the retina, so that instead of an image we have a circle of diffusion on the fundus, the total illumination of which is equal to that of the pupil, while the intensity of illumination will be inversely proportional to the size of the surface illuminated.

When using a plane mirror, the distance (D) of the immediate source of light from the eye is equal to the distance of the light from the mirror (l) plus the distance (d) of the mirror from the eye :

$$D = l + d.$$

The nearer we bring the mirror to the eye, the brighter the image.

In the case of a concave mirror, D diminishes with the distance of the light from the mirror, and with the distance of the mirror from the eye, but increases as the focal length increases

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}.$$

We use concave mirrors to cast convergent rays into the eye,

since we are able to use rays of different divergence much more conveniently with a plane mirror, as we have shown above.

Suppose we use a concave mirror to project a cone of luminous rays 25 cm. in height ; only those rays which enter the pupil will fall upon the retina. If now we hold the mirror very near to the eye, only a very few rays will enter the pupil, the majority being scattered upon the face and elsewhere. If we now withdraw the mirror, the luminous intensity of the part of the reflected cone of light which engages the pupil becomes greater and the maximum is reached when the apex of the cone coincides with the pupil, that is, when the mirror is at a distance of 25 cm. from the eye. Hence such a mirror gives the best illumination when used at this distance, and such a mirror is commonly used in the examination of the eye by the indirect method.

Mirrors of very short focal length are not useful, because of the great diffusion of their reflected images, and experience shows that the radius of curvature should not be less than 12 cm., and this is the mirror which is commonly used for direct ophthalmoscopic examination. Although we are not able to use the maximum illumination power of the mirror (we hold it at about 20 mm. from the eye) concave mirrors improve the illumination of the retina by causing an overlapping of the circles of diffusion upon the fundus from a source of light not uniformly luminous, and so equalising the brightness of the retinal image.

Provided the eye accommodate for the immediate source of light, the brightness of the retinal image is the same whether the mirror be plane, concave or convex. We know that the quantity of light which enters the eye from a given source is inversely proportional to the square of the distance of the source from the pupil ; we also know from our consideration of the pinhole camera that the area of the retinal image is also inversely proportional to the square of the distance of the object from the pupil. Consequently, the intensity of illumination of the retinal image is constant, whatever may be the position of the object.

The Apparent Brightness of the Ophthalmoscopic Field.—When we examine the fundus of the eye, only that portion of the cones of luminous rays that can pass through the pupil

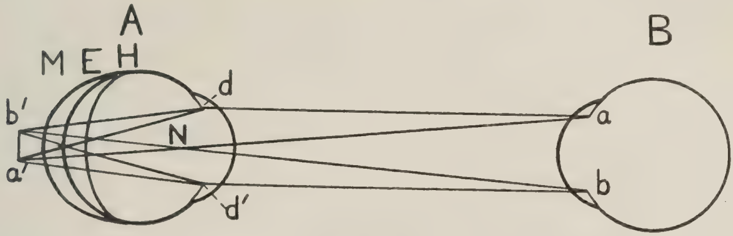


Fig. 141.

of the observer can reach his retina, and the maximum illumination will occur when rays emanating from the fundus of the observed eye are able to cover completely the pupillary area of the observer.

Taking the rays that delimit the ophthalmoscopic field, *a′b′* is the image of the pupil *ab* of the observer. The cone of rays from the retina of the emmetropic eye will completely cover the pupil of B ; rays from each point of the hypermetropic fundus will also cover the pupil at B ; in the fundus of the myopic eye no point of its surface is able to send out a cone of rays corresponding to each point of *a′b′*.

Consequently, the fundus appears least bright in myopia, brighter in emmetropia, and slightly more bright in hypermetropia than in emmetropia.

In the indirect method each point of the retinal image of the pupil of the observer is able to send out a cone of luminous rays which will cover completely the pupil of the observer in all conditions of refraction, consequently, nearly the whole area of the ophthalmoscopic field is of maximum brightness.

CHAPTER VI

RETINOSCOPY

If a source of light be held before a convex lens at a distance greater than its focal length, an inverted image of the source will be formed on the other side of the lens which may be received by a screen placed in a suitable position. If the screen be held at the conjugate focus of the source of light a sharp image will be seen, whilst if the screen be held nearer to or

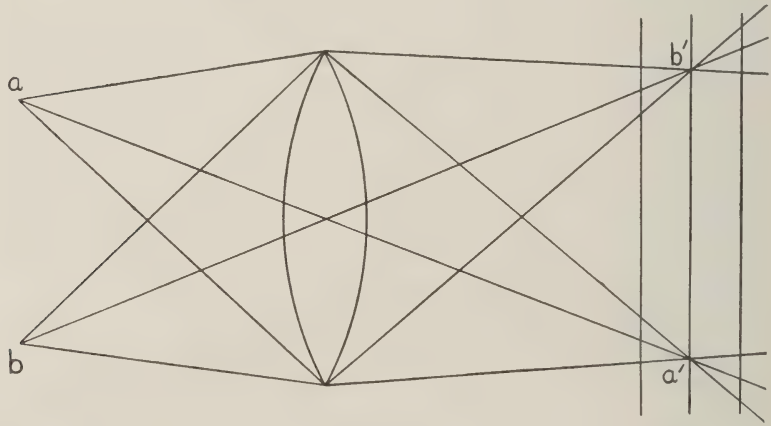


Fig. 142.

farther from the lens than the conjugate focus, a diffuse image will be formed.

If the source of light *a* be moved to another position *b*, then a similar image will be formed at *b*′, and it will be noticed that, whereas the source has been moved in a downward direction, the image has crossed the screen in the opposite direction, that is, upwards.

Take now the diagrammatic eye, and let *HEM* represent the position of the fundus in hypermetropia, emmetropia and

myopia. It will be seen that if a source of light be moved in front of the eye, an image of the source crosses the fundus

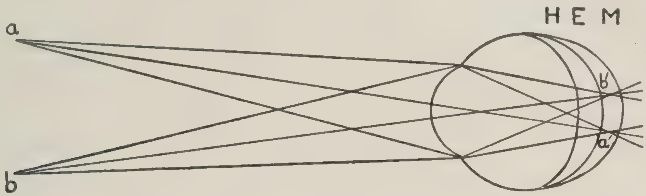


FIG. 143.

in the opposite direction, and it matters not if the eye be emmetropic, hypermetropic or myopic.

THE CONCAVE MIRROR.

If a light L be placed behind a patient's head at a distance of about 150 cm. from a concave mirror of focal length equal to 25 cm., then a real inverted image of the source L is formed in front of the mirror at a distance of 30 cm. at a.

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f} \therefore \frac{1}{v}=\frac{1}{25}-\frac{1}{150}=\frac{1}{30}$$

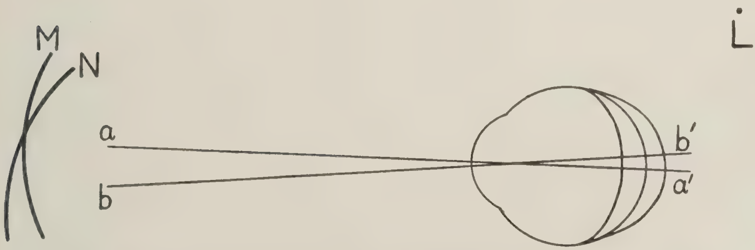


FIG. 144.—The Real Movement of the Light on the Fundus with the Concave Mirror.

With the mirror in position M an image of a will tend to be formed at a' on the fundus of the eye, and if the mirror be rotated around a horizontal axis in a downward direction to N, then the image of the source of light will also move downwards to b in the same direction as the movement of the mirror, and the illuminated area on the fundus of the eye will move upwards.

We may, therefore, say that when a concave mirror is used the illuminated area on the fundus moves in the opposite direction to the movement of the mirror, and also to the movement of the light reflected from the mirror upon the face of the patient.

The Plane Mirror

An image formed in a plane mirror is virtual, erect, the same size as the object, and is situated the same distance behind as the object is situated in front of the mirror. Furthermore, if a plane mirror be rotated, the image moves in the opposite direction to the movement of the mirror.

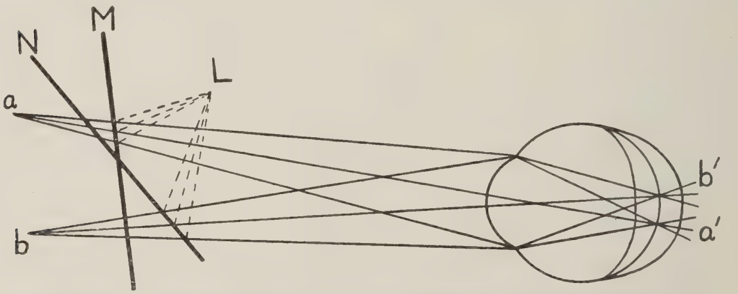


Fig. 145.—The Real Movement of the Light on the Fundus with the Plane Mirror.

Let *M* be a plane mirror, and *L* a source of light, and let *a* be the image formed by the mirror which will give rise to an illuminated area *a′* on the fundus of the eye.

Rotate the mirror about a horizontal axis in an *upward* direction into position *N*; it will be noticed that the image of the source *L* has moved *downwards* to *b*, and the illuminated area on the fundus has moved in an *upward* direction to *b′*.

Therefore, with a plane mirror, the illuminated area on the fundus moves in the same direction as the mirror, and in the same direction as the movement of the light reflected from the mirror on to the face of the patient.

The source *L* is spoken of as the *original* source of light, and the image produced by the mirror as the *immediate* source The actual movement of the illuminated area on the fundus is

called the *real movement* of the light, as if it were observed from behind the eye through a hole cut in the sclera.

In retinoscopy we observe through the hole in the mirror the *apparent* movement of the light as it is reflected back to us and influenced in its behaviour by the refractive media of the eye.

In Emmetropia.—An emmetropic eye is one in which with the accommodation at rest parallel rays come to a focus upon the retina, and, owing to the reversibility of rays in optics,

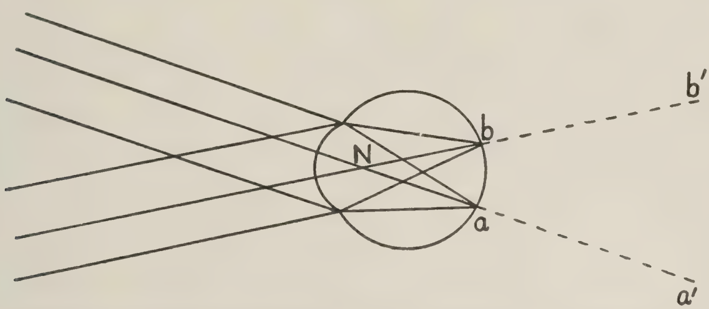


FIG. 146.—The Apparent Movement of the Light on the Fundus in Emmetropia.

rays emanating from the retina will leave the eye in a parallel direction.

Take the point *a* on the fundus of the emmetropic eye ; as the rays leaving the eye are parallel in direction they will be projected by the observing eye to a position *a′* behind the observed eye. Let the immediate source of light be moved so that the light on the fundus moves to position *b* ; the rays from this area will be projected by the observer to position *b′*, and the movement observed will be from *a′* to *b′*, that is, the apparent movement of the light is in the same direction as that of the real movement, which is from *a* to *b*.

In Hypermetropia.—A hypermetropic eye can focus only convergent rays upon the fundus, and, consequently, a luminous area upon the fundus will give rise to rays that leave the eye in a divergent direction.

Take the point *a* on the fundus of the hypermetropic eye ;

as the rays leaving the eye are divergent they will be projected by an observer to the point from which they appear to diverge,

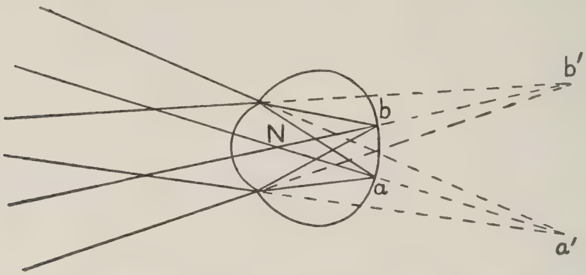


FIG. 147.—The Apparent Movement of the Light on the Fundus in Hypermetropia.

namely, to a', the conjugate focus, or punctum remotum of the eye. Similarly, from the point b, the rays will be projected to the point b', so that the apparent movement observed will be from a' to b', that is, in the same direction as the real movement.

In Myopia.—A myopic eye is able to focus only divergent rays upon the fundus, and so a luminous area upon the fundus will give rise to rays which leave the eye in a convergent direction, and come to a focus giving rise to a real inverted image of the luminous area at some point between the eye and infinity.

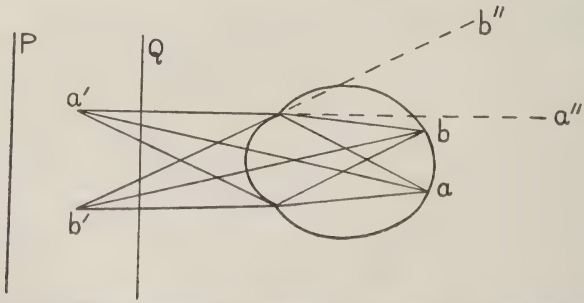


FIG. 148.—The Apparent Movement of the Light on the Fundus in Myopia.

The apparent movement of the light upon the fundus depends upon whether the observer is situated beyond the conjugate focus, *i.e.*, the punctum remotum of the myopic eye, or nearer

to the eye than the point at which the rays emanating from it come to a focus.

Let us take an observer at P. Here will be seen an inverted image a' of the point a, and similarly the point b will give rise to an inverted image at b'. The real movement of the light is from a to b, but it will appear to the observer to be from a' to b', and so the apparent movement will be in the opposite direction to the real movement.

Suppose the observer to be at Q so that he will receive rays from the fundus before they have come to a focus, the rays from a will be projected to a'', and those from b to b'', and the apparent movement will be from a'' to b'', that is, in the same direction as the real movement.

Therefore, in myopia, the apparent movement will be in the opposite direction to the real movement when the observer is beyond the punctum remotum of the eye, but the apparent movement will be in the same direction as the real movement when the observer is within the punctum remotum.

It should be noticed that in emmetropia and hypermetropia we observe a virtual erect and magnified image of the luminous area on the fundus, whose movement, naturally, is in the same direction as that of the actual luminous area, and the same conditions exist when observing the movement of the luminous area on the fundus of the myopic eye from a point within the punctum remotum. It is only when we are beyond the punctum remotum that we see an inverted image of the luminous area whose movement is naturally in the opposite direction to that of the actual luminous area on the fundus.

Now there must be in the myopic eye some point between the eye and infinity, where the virtual erect image, whose movement is in the same direction as the luminous area on the fundus, gives way to the real inverted image with a movement in the opposite direction. This point is called the *point of reversal*, and if the observer is situated exactly here no movement of the light can be observed, but the pupil, with the immediate source of light in one position, is bright, and when the immediate source is moved, gradually becomes dark.

The Light on the Fundus.—The shape of the illuminated area depends upon the shape of the original source of light, and since in practice the original source is round, so, therefore, is the retinal image round.

The illuminated area of the fundus is very minute. With a plane mirror, an original source of light 25 cm. behind the patient's head, and 25 mm. in diameter, and the observer 1 metre in front of the patient, the immediate source of light will be approximately 2·5 metres from the patient.

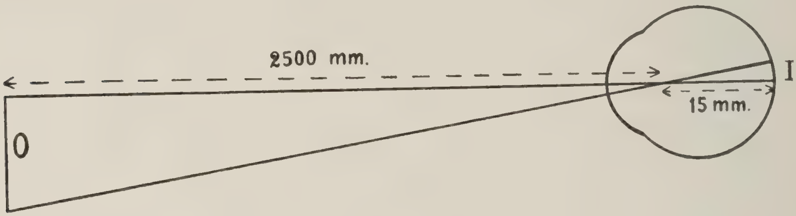


Fig. 149.

The diameter of the retinal image is therefore :

$$= \frac{25 \times 15}{2,500} = 0·15 \text{ mm.}$$

that is, less than the diameter of a large vessel of the retina. If a linear source of light be used, then the image upon the fundus will be linear as the circles of diffusion, by overlapping, will not be able to produce a circular image.

The portion of the illuminated fundus actually seen at any one moment corresponds to the ophthalmoscopic field, and is, therefore, smaller than the field of illumination. Consider an eye with 1 dioptre of myopia, and the eye of the observer at a distance of 1 metre from the patient. An image of the pupil of the observer will be formed exactly on the retina of the patient, and this, as we have seen, measures the ophthalmoscopic field. The distance of the nodal point of the observed eye from the retina is 15 mm., the diameter of the pupil of the observer is, say, 4 mm., and the distance of the eyes

tapar 1 metre, consequently the diameter of the image of the observer's pupil upon the retina is given by this equation :

$$\frac{4 \times 15}{1,000} = \cdot 06 \text{ mm.}$$

This tiny area is the only portion of the illuminated fundus visible, the surrounding fundus is in darkness, consequently, if the immediate source of light be moved, the illuminated area on the fundus will be succeeded by a dark area, usually called the shadow. If, then, in an eye, approximately emmetropic, we observe the illuminated area, it will be circular in outline and fill the pupil with a red glow ; as the patch moves across the fundus it will be followed by an area of darkness. It is the junction between the area of illumination and the non-illuminated area that we observe when deciding the direction of the movement of the light on the fundus, and it is usual to speak of the movement of the shadow in relation to that of the mirror.

If there is a considerable difference in the refraction of the two principal meridians, there being, therefore, a difference in magnification of the illuminated area, it will be oval instead of round in shape, the inclination of the major axis of which gives important information as to the angle at which a cylinder must be placed to give equal magnification in all meridians, in other words, by the combination of a sphere and cylinder render all meridians of the eye of equal refraction.

Now the *intensity of the illumination* of the fundus depends upon several points :

(1) The intensity of the original source of light ;

(2) The form of the mirror, whether flat or concave ;

(3) The distance of the original source of light and the mirror ;

but most upon—

(4) The refraction of the observed eye.

If the light is perfectly focussed upon the retina, the area will approximate to a point, and the intensity of illumination will be at its maximum, and this will be the case when the conjugate focus of the eye coincides with the immediate source of light.

With a plane mirror and the light 50 cm. behind the examined eye, the immediate source of light will be 2·5 metres in front of the examined eye, so that the intensity of illumination will be greatest when the conjugate focus of the eye is at 2·5 metres, that is, when it has a myopia of 0·4 D.

With a concave mirror of 25 cm. focal length, and the original source of light 50 cm. behind the examined eye, and the observer seated 1 metre in front of the eye, the immediate source of light, using the formula $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$, will be at a point 30 cm. in front of the mirror, that is, 70 cm. in front of the eye. Therefore the intensity of illumination will be greatest when the conjugate focus of the eye is 70 cm. in front of it, that is, when the eye has a myopia of about 1·4 D. With an eye of, say, 10 dioptres of myopia, and a conjugate focus, therefore, of 10 cm., the immediate source of light, especially with the plane mirror, will form a very diffuse image on the fundus, consequently, the reflex will be dull as the illumination is poor, owing to the light being spread over a much larger area of the fundus.

This observation is of clinical value when deciding whether an eye has a high or low degree of ametropia.

The Rapidity of Movement of the Illuminated Area.—The rapidity of the *real* movement on the fundus depends upon :

1. The rapidity of movement of the mirror.
2. The distance of the mirror from the observed eye.
3. The distance of the original source of light from the mirror.
4. The distance between the fundus and nodal point of the observed eye.

The real movement of the light on the fundus necessarily affects the *apparent* movement, that is, the movement of the illuminated area as observed through the refractive media of the eye, but, as with the intensity of illumination of the area on the fundus, the most important factor is the refraction of the observed eye.

An emmetropic eye is similar to a convex lens with a screen

in the plane of its principal focus. Looking through the lens at an object on the screen in these circumstances the object will appear under considerable magnification, and the magnification will be so great that the area of the lens will be occupied by an image of only a small portion of the object on the screen. If now the object be moved, the image of the portion of the object will move very rapidly, the movement of the object being magnified *pari passu* with its area.

With the object in any other relation to the focal length of the lens the magnification will be less, and, consequently, the apparent movement will be less the farther distant the object from the principal focus of the lens in either direction, that is, the nearer to or farther from the lens. As myopia and hypermetropia correspond respectively to a convex lens with the screen (the retina) farther from the lens than its principal focus, on the one hand, and nearer to the lens on the other, we may say that the higher the degree of ametropia the less rapid the apparent movement of the illuminated area on the fundus.

Astigmatism.—In astigmatism we see the illuminated area through a medium whose magnifying power differs in the two principal meridians. Thus, one meridian may be emmetropic, causing maximum magnification, whereas the other may be hypermetropic, that is, with the illuminated area nearer to the refracting medium than its principal focus, and, as a consequence, less highly magnified. The result will be that the illuminated area will appear as an oval with its major axis lying in the meridian of emmetropia. As the illuminated area is infinitely magnified in the meridian of emmetropia the sides of the oval will appear as straight lines.

The illuminated area is, therefore, oval in outline in astigmatism, the major axis of the oval lying in the meridian of least ametropia, and thus is produced the band of light, the inclination of which gives such valuable information as to the direction of the axis of the cylinder which will correct the meridian of greatest ametropia.

In other words, in order to make this meridian emmetropic,

so as to correspond with the other meridian, a cylindrical glass, with its axis in that of the band of light, must be placed before the eye until the magnification in each meridian is the same.

The oval shape of the illuminated area, and still more, the appearance of a band of light will only be apparent when there is a considerable difference in the refraction of the two principal meridians, and the student must not conclude that all cases of astigmatism exhibit this peculiarity. When, by means of a glass, one meridian has been rendered emmetropic we are then able to appreciate the banded appearance, and usually it is only during the course of the investigation of the refraction of an eye by retinoscopy that the banded appearance is obtained. The greatest contrast will be obtained when the observer's eye is at the point of reversal of one meridian (giving the sharpest image) and the immediate source of light is at the point of reversal of the other meridian giving the brightest illumination in that meridian.

In retinoscopy the points of reversal of the meridians of greatest and least refraction are determined, and so the value of the interval of Sturm is determined, which represents the astigmatic error.

Aberration.—A. *Positive.*—In common with other lens systems the eye suffers from spherical aberration. With the ordinary convex lens, the refractive power of the peripheral part, is greater than that of parts nearer the principal axis, and this, the more common, is known as positive spherical aberration.

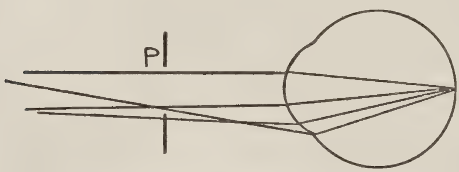


FIG. 150.—The Paracentral Shadow.

Taking an emmetropic eye with marked spherical aberration, the rays leaving the central area of the cornea will be parallel in direction, and, consequently, will enter P, the pupil of the observing eye. Take now a ray a little to one side of the centre of the cornea ; by the greater power of this portion of the refracting media of the eye, it will be rendered convergent, but

not sufficiently so to cause it to strike the pupil of the observer's eye. It will, therefore, strike the iris outside the pupil and will not be seen by the observer. A more peripheral ray still will be more refracted, and will enter the pupil of the observer, and the appearance, therefore, will be of a more or less brilliantly illuminated central area of the observed pupil, outside which will be a less brilliantly illuminated area, succeeded again by a more brilliantly illuminated area.

The less well-illuminated area, which is in the shape of a ring, is also known as the *paracentral shadow.*

Spherical aberration of the eye is much more easily seen after the use of a mydriatic, which exposes the peripheral portion of the lens, and its existence should impress upon the student that the only observations of value in examining the refraction of an eye by retinoscopy are those on the central portion of the cornea opposite the pupil, an area about 4 mm. in diameter.

B. *Negative.*—In this rarer condition the central portion of the media of the eye are more refracting than the peripheral, the most extreme example of the condition being seen in cases of conical cornea. Here the central part of the cornea bulges forwards in the shape of a cone so that the refraction in this area becomes myopic, and as the cornea gradually flattens towards the periphery, so the refraction becomes less myopic. As has been explained above, the result is that the peripheral portion of the reflex from the illuminated area of the fundus moves more quickly, with a given movement of the mirror, than the central part, and as a result the peripheral portion of the reflex spins round the central portion giving the condition its characteristic appearance.

The occurrence of aberration causes many of the difficulties of retinoscopy, since we see different parts of the reflex from the illuminated area of the fundus moving in contrary directions. This difficulty is overcome in practice by paying attention only to the movement in the central portion of the cornea.

The Point of Reversal. When the point of reversal is reached no movement of the light across the fundus is seen, but the

pupil of the observed eye with one position of the mirror is bright, and with another position dull, and as the mirror is still further moved, the pupil becomes dark.

What is the condition which at this moment produces these results ?

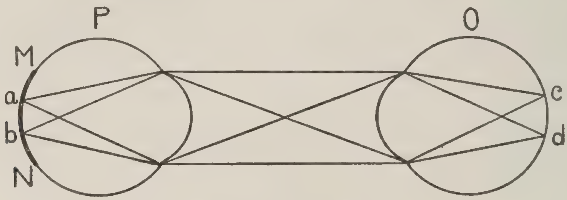


FIG. 151. (Bjerrum.)

The above diagram represents the path of rays when the point of reversal is reached. P is then accommodated for the pupil of O, the observer, and O is accommodated for the pupil of P, as occurs in all stages of retinoscopy. *ab* on the fundus of P is, therefore, the image of the pupil of O, and *cd* is the image of the pupil of P on the fundus of O, and also *ab* represents exactly that part of the fundus of the eye P that O is able to see at any one moment. It represents the ophthalmoscopic field of vision. No point of the fundus of the eye P outside the region *ab* will be able to send out luminous rays into the pupil of O, and *each* point of the surface *ab* sends out light to the whole area *cd.*

MN is that part of the fundus of the eye P that is illuminated ; it is larger than the ophthalmoscopic field *ab*. If the illuminated area is moved so that the point *M* reaches the point *a*, O will not observe any alteration in the illumination of the pupil, because the part *ab* is always illuminated. If the movement of *MN* is continued in the same direction the point *a* will pass into darkness, and, consequently, the area *ab* will no longer reflect so much light. It follows that from that moment the area *cd* of the fundus of the eye O will receive less light, and this diminution of illumination is distributed uniformly on the whole surface *cd*. As *MN* is further displaced the same is the fate of each part of *ab*, and when, finally, the point *b* is the only one sending out light to the pupil of O, the whole area *cd* will be but feebly illuminated, and when *MN* has passed the

area *ab* completely, the fundus of O receives no light from P, that is, the pupil of P will appear quite dark.

We have seen that the apparent movement of the light on the fundus tells us that, on the one hand, an eye *may* be either emmetropic, hypermetropic or myopic, with the punctum remotum behind the point from which the observation is made, or *actually is* myopic with its punctum remotum between the observer and the observed eye. The information is, therefore, only definite in the case of myopia of certain degree, and we may say that retinoscopy is a test which is only applicable to a condition of myopia.

If we take an emmetropic eye from which parallel rays are emanating, and we place in front of it at its anterior principal focus a + 1 D spherical lens, those parallel rays will be brought to a focus at the principal focus of the lens, that is, roughly, 1 metre from the eye. We have seen that the measure of myopia is the distance of the punctum remotum or conjugate focus from the eye, which expresses in centimetres the focal length of the lens which will correct the error. Thus, if we know the distance of the punctum remotum from a myopic eye, we know the dioptric value of the correcting lens.

In applying retinoscopy to the myopic eye we might, by altering our distance from the eye, walking nearer to or farther away from the eye, find the point of reversal, and then, with a suitable measure, make a note of the distance of the point of reversal from the eye.

The other method would be to take our position in front of the eye at a known measured distance, and place lenses in front of the eye until the punctum remotum of the observed eye coincided with the nodal point of the observer's eye. By this means, not only can we discover the refraction of the myopic eye, but, since the method consists in producing an artificial myopia, of the emmetropic and hypermetropic eye as well. We have shown above that the placing in front of an emmetropic eye of a convex lens of 1 D induces an artificial myopia of 1 D, and similarly by placing a suitable convex lens in front of a hypermetropic eye we can produce an artificial myopia

which can be calculated by measuring the distance of the point of reversal.

This method is the one adopted in the application of retinoscopy to clinical ophthalmology, and for convenience we place in front of the eye a lens of such a strength that we induce in every case 1 dioptre of myopia. In this way, by making our observations at a measured distance of 1 metre, we are able to deduce the refraction in all cases.

Now that we have considered the optical basis of retinoscopy we are in a position to discuss its practical application.

For the sake of convenience, the distance chosen at which observations are made in retinoscopy, is 1 metre. With this distance separating surgeon and patient, the surgeon can place suitable lenses in the frame on the face of the patient, he can remain seated, need not walk about, and can see quite distinctly the play of light and shade in the pupil of the patient. For the most accurate work a long working distance would be chosen, and for this reason: suppose that the distance chosen for observation be 2 metres; with the point of reversal at 2 metres distance from the eye, the eye will have 0·50 D of myopia; an error of 25 cm. in the distance between the surgeon and patient will lead to but ·07 D error in the correcting lens. If, on the other hand, a distance of 50 cm. be chosen, where the point of reversal will be equivalent to 2 D of myopia, an error of 10 cm. in the distance between surgeon and patient will cause an error of 0·5 D in the correcting lens.

At a distance of 2 metres the surgeon would not be able to remain seated and reach the patient, but would constantly be moving backwards and forwards, and although a distance of 50 cm. allows an excellent view of the play of light and shade in the pupil of the observer, it allows but a small margin for possible errors in observation; the distance of 1 metre is convenient, and allows a fair margin for possible error, for which reason it has been chosen almost universally as the distance at which observations are made. At distances greater than 2 metres it is difficult to see the play in the pupil. The room should be thoroughly darkened, not only to reduce reflexes

from the cornea of the patient, but also to give the greatest contrast between the illuminated area on the fundus, and the dark unilluminated area around.

The source of light should be small and of great brilliance, such as a "Fullolite" electric lamp, obscured by an opaque hood in the side of which is cut a hole opposite the brightest part of the filament, and controlled by a diaphragm of some kind, an aperture of 10 mm. being convenient.

As a rule a plane mirror is used in preference to a concave, at any rate, to a concave mirror of short focal length. The sight hole should be of 3 mm. diameter, made by removing silvering from the back of the mirror and not by drilling the glass, a process that leads to annoying reflexes at the edges of the hole, especially if the cut edges become chipped.

If a larger sight hole be made, there appears a lacuna in the light patch produced by the mirror which reduces the illumination of the light area on the fundus of the eye.

A larger hole, which has advantages of ease in use, may be used, if, instead of a plane mirror, we use a concave mirror such that its focal length is greater than the distance separating surgeon and patient. Thus, with a concave mirror of 150 cm. focal length, with the original source of light 125 cm. distant, a virtual and magnified image of the light is formed 750 cm. behind the mirror. As a result the rays of light are less divergent than with a plane mirror, the illumination is therefore greater, and for the same reason the lessening of illumination caused by scraping away the silver to make the sight hole is hardly noticeable. This, the Lister mirror, may well be recommended to the student.

The most important observation that has to be made in retinoscopy is at the moment that the point of reversal of the light on the patient's fundus coincides with the observer's nodal point, consequently, at this moment the brilliance of the luminous area on the fundus should be at its greatest, its definition sharpest. We have shown above that the illumination and definition of the luminous area is greatest when the immediate source of light is at the conjugate focus of the eye,

consequently, for the most accurate observation the nodal point of the observer's eye and the immediate source of light should coincide with the point of reversal, that is, the conjugate focus of the retina at that particular moment.

With the plane mirror this may be accomplished by hanging the original source of light quite near to the mirror, so that its image, that is, the immediate source of light, is only a very short distance behind the mirror. This, of course, can only be accomplished with a light partially obscured by a hood or with a retinoscopy mirror illuminated by an electric attachment so that the luminous bulb is very near to the mirror.

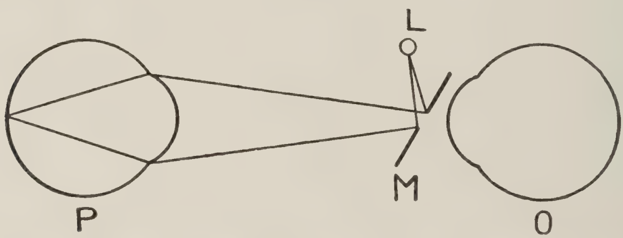


Fig. 152.—The most favourable relative position of light and mirror for observing the point of reversal.

In astigmatism the meridians, in which the refraction is respectively greatest and least are placed at right angles to each other, and, as a rule, so placed that the meridian of least refraction is horizontal and the other vertical ; therefore, in an astigmatic eye we follow out the same manœuvre in a plane at right angles to that in which we previously rotated the mirror.

Now it is convenient to know as accurately as possible the inclination of these meridians to a horizontal or vertical line as then we shall be able to indicate precisely the angle at which the cylindrical glass shall be inclined so as to render all meridians of equal refraction.

When one meridian has been corrected by a suitable sphere the luminous patch on the fundus will have been highly magnified in that meridian and, as we have seen, its edges have become more or less linear ; but the contrast between this and the surrounding darkness is not great, because we have so

arranged the immediate source of light that the best illumination of the fundus is in the meridian of best definition and greatest magnification. If we could so arrange the immediate source that it coincided with, or, at any rate, approximated to the point of reversal in the meridian at right angles we should then have the greatest contrast, the best definition in one meridian, the best illumination in the other. This may be accomplished in myopia by bringing the observer's eye and mirror to the point of reversal of the meridian of greatest myopia, and, with the mirror held in this position, pushing the original source of light behind the patient so that the immediate source of light will retreat behind the mirror, and so come to coincide with the point of reversal of the less myopic meridian.

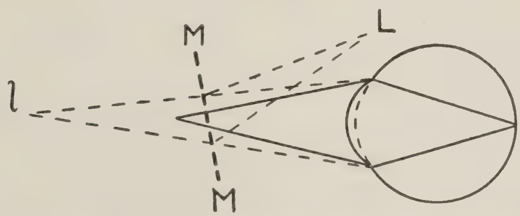


FIG. 153.—The most favourable relative position of light and mirror for observing the band of light in astigmatism.

In the hypermetropic eye we first bring the meridian that is more myopic (that is, *less* hypermetropic) to a point of reversal at 1 metre distance with a suitable lens, and then pushing off the original source of light from the mirror, we bring the rays divergent from the immediate source of light nearer to the point of reversal in the other meridian, and, consequently, the illumination in this meridian is better than in that meridian of which the point of reversal has been determined.

If no astigmatism is present the arrangement of light and mirror will not cause the bright band to appear since the magnification of the luminous area on the fundus is the same in all directions. However, the illuminated area becomes magnified more and more as the point of reversal is approached, so that the edge of the reflex is no longer round, but appears as a straight line.

Although when the bright band in astigmatism is found we try to move our mirror about an axis parallel to the edge of the band, nevertheless, we find that even when the movement of the mirror does not correspond with this axis, the movement of the band is always at the same inclination. This apparent movement of the band of light, always at right angles to the direction of the corrected meridian, is an optical illusion.

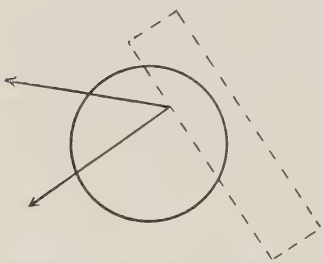


Fig. 154.

If a straight edge, obliquely placed behind a circular aperture, be moved either horizontally or in a direction at right angles to the edge it will appear always to be moving in a direction at right angles to the edge.

Such, then, are the appearances of regular astigmatism in which, speaking generally, the refraction in any particular meridian is the same throughout the visual area of the cornea. In irregular astigmatism such as is seen after corneal ulceration and disease, the refraction varies in different parts of the pupil, even in the same meridian. Irregular astigmatism is frequently seen in lenses the subject of early cataract changes, even before definite irregularities and opacities can be seen with the ophthalmoscope. Another form of irregular astigmatism invading the pupillary area is that giving rise to the so-called "scissors movements." In this condition one part of the pupillary area is more myopic than another, causing a different movement in one part of the pupil from that in another, so that, in one portion, the more myopic, there is movement against the plane mirror, and in another portion movement with the mirror. It is the peculiar opening and shutting, as it were, of the light area that gives the appearance its name. The condition may be produced artificially in a model eye by tilting the lens, and, if light be reflected in a very oblique direction, in the living eye as well.

The Method of Performing Retinoscopy with the Plane

Mirror.—The patient and surgeon are seated facing each other at a distance of a metre measured from the external angular process of the frontal bone of one to the other. In the first instance this distance should be measured so that the student may fix the actual distance in his memory, as it is usually very much under-estimated. A test frame is placed on the face of the patient, who is told to fix the middle of the surgeon's forehead. One eye is covered by an opaque screen. For the inexperienced observer it is wiser to have the accommodation paralysed with a mydriatic, a procedure not uncommonly required by an experienced refractionist. The light, in the first instance, is placed either above or to one side of the patient's head so that the face is in shadow, and, as has been stated above, it is better to have the light covered by an opaque hood with a diaphragm opening in the side. With the mirror, held in a position before the observer's eye, light is reflected on to the patient's face and into his pupil. A red glow will be seen in the pupil, caused by light being reflected from the fundus of the patient to the observer, who projects this to the pupil of the patient, the object for which the observer accommodates throughout.

It is advisable for the observer to wear spectacles, if necessary, so as to improve his vision to 6/9, and if he be presbyopic, his correction for near objects as well.

The glow in the pupil will be bright or dull depending largely upon the degree of ametropia : in dark complexioned individuals the reflex is relatively dull.

It is to be remembered that our attention must be fixed upon the central part of the pupil, an area about 4 mm. in diameter.

The mirror is rotated about its horizontal diameter, and the light reflected upon the face will move in the same direction as that of the mirror. We know that with the plane mirror this is the direction of the *real* movement of the light across the fundus of the eye. The *apparent* movement is carefully watched and we will suppose that it is in the same direction as the movement of the mirror. In that case, the eye in that meridian is either emmetropic, hypermetropic or myopic by less than 1 D.

We must judge by the illumination and rapidity of movement of the light whether the degree of ametropia is high or low.

If the illumination be poor and the movement slow, and, moreover, the edge of the illuminated area circular in outline, that is, the magnification low, we may judge that there is a considerable degree of hypermetropia ; we therefore place in the cell of the frame a convex lens of, say, 4 D value. We again rotate the mirror, and note if the direction of movement of the reflex is still with, or is now against that of the mirror, and we will increase or reduce the strength of the lens until the movement ceases. We now know that the punctum remotum of the eye in this meridian is at our own nodal point, and that the eye in the meridian of movement of the mirror has 1 dioptre of myopia.

If, on the other hand, before the lens was placed in the frame, the illumination was good, the movement swift and the edge of the illuminated area straight, or, at any rate, only slightly curved, we then know that the hypermetropia is of very low degree, or the eye either emmetropic or myopic of less than 1 dioptre. We, therefore, place in the cell of the frame a low convex glass, 0·50 D to 1·00 D, and observe the result. If the movement in the pupil is abolished by a convex glass of 0·50 D we know that this glass has produced 1 dioptre of myopia in that meridian, and, consequently, the real refraction of the eye in that meridian is 0·50 D of myopia.

If on placing a 1 D convex lens in the frame the movement of the light and shadow ceases, we know that the point of reversal is at our nodal point, and the added lens has produced in the eye 1 dioptre of myopia. The refraction of the eye must, therefore, be emmetropic.

If the + 1 D lens does not abolish movement in the pupil of the observed eye, then we add stronger and stronger convex lenses, until the point of reversal is reached, as the eye has been proved to be hypermetropic.

If the movement of the light is against the movement of the mirror, the eye must be myopic of such a degree that the punctum remotum is between the observer and the observed

eye. The eye has, therefore, more than 1 dioptre of myopia, and to reach the point of reversal concave lenses must be placed in the frame.

In this way, then, we determine the refraction in one meridian, and if the error be spherical, that is, simple hypermetropia or myopia, we shall find that with the lens in place in the frame a rotation of the mirror at right angles to the previous movement shows that the point of reversal has also been reached in the meridian at right angles to that just studied. If, however, we find that there is movement of the light in the pupil on rotating the mirror in the meridian at right angles, then the eye is astigmatic.

We know that regular astigmatism, which is mainly corneal, is usually such that the curvature of the cornea in the vertical meridian is greater than that in the horizontal meridian, that is, that the dioptric value of the cornea in the vertical meridian is the greater. It is, therefore, a habit of practice to correct the vertical meridian first in hypermetropia, and the horizontal first in myopia. The reason of this method is this : astigmatic errors are corrected by the use of spheres with a superadded cylinder. In hypermetropia the added convex lenses increase the dioptric value of the eye in all meridians, and when appropriately used, give us the point of reversal of one meridian, leaving us the other meridian to be corrected with a superadded cylindrical lens of the same sign as the sphere.

In myopia the added concave lenses reduce the dioptric value of the eye, and so we first reduce the dioptric value of the less powerful meridian, that is, the horizontal, and so find its point of reversal, leaving the vertical meridian to be corrected with a concave cylindrical lens.

It has been explained that the most accurate observations at the point of reversal are made if the hooded light is placed as near the mirror as possible. If the eye be astigmatic the light is now placed behind the observed eye, so that we may see the inclination of the band of light caused by reflecting the light from the mirror into the eye, and of this a note is made.

Two methods of procedure are now open to us, the first, and

more usual, is to correct the meridian at right angles to the band of light with spherical lenses (in exactly the same manner as we have corrected the meridian parallel to the band of light) with the light as near to the mirror as possible, and this method has the advantage of being simple, and requiring a box of spherical lenses only. When the point of reversal is reached in this meridian, it will, with the light in an appropriate position, cause a band of light with a contrary movement to appear in the meridian at right angles, and we are, therefore, able to confirm or correct our previous finding of the inclination of the band of light in the opposite meridian.

The second, and more accurate method is to leave in place the spherical lens which corrects one meridian, and then add suitable cylindrical lenses with their axes in that of the band of light until the point of reversal is reached in the other meridian. If the value of this cylinder is correct we find that upon moving the mirror in any meridian all movement of the light in the pupil has been abolished, and we have merely the appearance of illumination in the pupil, followed by less and less intensity of illumination as the mirror is moved until the pupil becomes quite dark, that is, the point of reversal in all meridians is now at our nodal point.

Let us suppose that the lenses used are + 4·00 D sph. with + 2·00 D cyl. axis 100°, to give the point of reversal in all meridians at 1 metre. We may apply a very delicate test to make certain that the cylinder used is of the correct value. If we approach the eye 25 cm., that is, place our nodal point 75 cm. from the observed eye, and again move the mirror in the two principal meridians we should obtain movement *with* the plane mirror in all directions, with equal rapidity of movement and equal intensity of reflex. Again, if we increase the distance between the two eyes to 125 cm., then we should obtain movement of the reflex *against* that of the mirror with equal

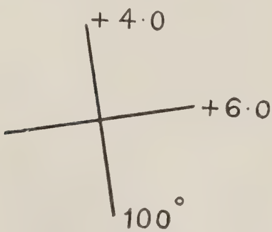


Fig. 155.

rapidity of movement in all meridians and equal intensity of reflex.

If the correction of astigmatism is incorrect, let us suppose that the cylinder should be + 2·25 D, instead of + 2·00 D, then on withdrawing to 125 cm. we shall find that in the meridian at 10° the light moves with the mirror or the movement has disappeared, whereas in the meridian at 100° there will be a band of light giving movement against the mirror.

If the angle of inclination of the cylinder is incorrect then we shall find that the principal meridians do not correspond with those for which the cylindrical lens is placed, and upon moving the mirror the light leaves the pupil in an oblique direction, and also there will remain apparently some uncorrected astigmatism. If the value of the cylindrical lens is correct, or too weak, its axis needs to be turned towards the axis of a similar lens that would correct the remaining astigmatism. If the cylindrical lens is too strong its axis needs to be turned towards the axis of a cylindrical lens of opposite sign that would correct the astigmatism.

If now the cylindrical lens be of correct value, and in the the appropriate axis, then any error that remains must be spherical ; this is corrected by altering the strength of the spherical lens.

By carrying out retinoscopy in this manner with spheres and cylinders, a great deal of time may be saved when the subjective testing is carried out in the same room without causing the patient to change his position. The lenses are left in the frames and the only alteration necessary when asking the patient to read the distant types is the replacement of the spherical glass in the case of hypermetropia by one of less numerical value, and in myopia by one of greater numerical value, corresponding to the myopia of 1 dioptre, which gives the point of reversal at 1 metre, the refracting condition of the eye left by the lenses used when the retinoscopy observation is carried out at the distance of 1 metre.

In mixed astigmatism it is usual to correct the hypermetropic meridian first, unless the error in the myopic meridian be

of low degree, when we should correct the hypermetropic meridian last.

The most useful method of recording our results is by a diagram, which shows the inclination of the two principal meridians.

Thus, if the error be spherical we make a cross with the two

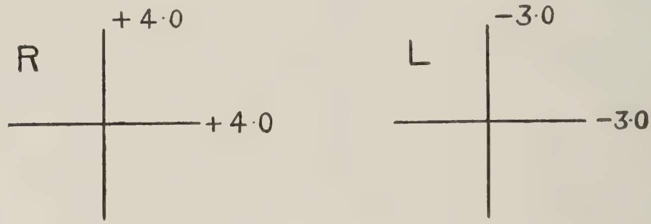


Fig. 156.

arms vertical and horizontal, and place at the ends of them the dioptric value of the lens which gives the point of reversal at 1 metre distance.

If the eye be astigmatic a similar diagram is used with a note

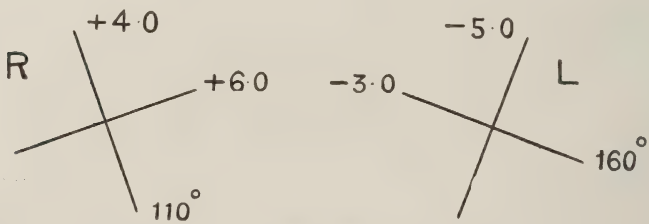


Fig. 157.

of the inclinations of the meridians, more especially of that meridian in which the axis of the cylinder is to be placed.

It must be remembered that these figures represent the dioptric values of the lenses that give a point of reversal at a distance of 1 metre from the eye, and, consequently, leave the eye myopic 1 dioptre in all meridians.

For instance, if the lenses which give a point of reversal at 1 metre are represented by :

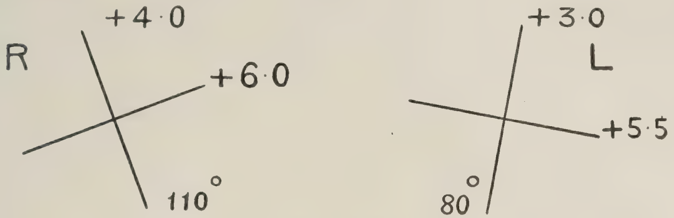


Fig. 158.

then the lenses that actually correct the ametropia are :

R + 3·00 D sph. + 2·00 D cyl. *ax* 110°

L + 2·00 D sph. + 2·50 D cyl. *ax* 80°

Astigmatism.—In recording the inclination of the two principal meridians in astigmatism, it is necessary that we should have some definite notation which may be understood by all who read printed records.

There has been a great variety of methods, but the best, without doubt, is that known as the "standard notation," which is the method used by physicists, manufacturing opticians, and now very extensively by ophthalmic surgeons. The meridians are measured and represented as the observer looks at the patient, and the radius vector starts in each eye to the right hand of the patient, at the point 0°, and then passes counterclockwise to the patient's left side, marking out the angular intervals from 0° to 180°.

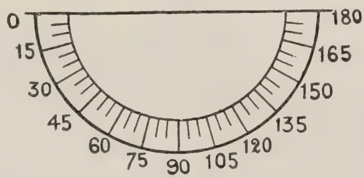


Fig. 159.

By this method ambiguity is prevented. This scale is engraved upon the face of the trial frame, so as to enable the

observer to note the inclination of the axis of the cylinder which corrects the astigmatism.

There are certain problems in considering the best combination of sphere and cylinder to order, since there are always two alternatives.

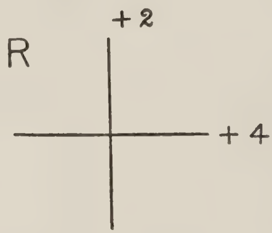


Fig. 160.

Suppose that in a case of compound hypermetropic astigmatism the lenses that correct the principal meridians are + 2·00 D. in the vertical meridian, and + 4·00 in the horizontal. We might order a combination

+ 1·00 D sph.
+ 2·00 D cyl. *ax* 90°
or
+ 3·00 D sph.
− 2·00 D cyl. *ax* 180°.

In this case the first combination is the better, as the lens is lighter and easier to make, and also its lower edge is less thick than in the second combination ; the prismatic effect, therefore, in the lower part of the lens is less in the first combination. This point is of especial importance in cases of anisometropia, in which the prismatic power of the lower part of the right and left lenses differs, and an artificial hyperphoria is introduced ; if, then, the lower part of the lenses be made unnecessarily thick, this effect will be increased. We therefore try, as far as possible, to keep the cylinders vertical.

In myopic astigmatism, in which the cylinder is so often horizontal, this may not be possible, but in mixed astigmatism it may often be accomplished.

In this case

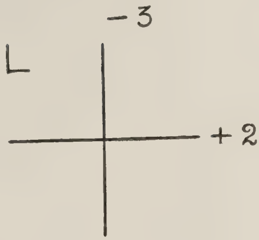


Fig. 161.

we might order

+ 1·00 D sph.
− 5·00 D cyl. *ax* 180°
or
− 4·00 D sph.
+ 5·00 D cyl. *ax* 90°.

On our previous plan we would order the second combination, since the cylinder is vertical. Apart from this, the second lens gives a periscopic effect, especially if the concave surface be placed next the eye, as we shall see from the following considerations.

There is always distortion, due to spherical aberration, when we look obliquely through a lens, the effect with spectacle glasses being that of an added cylinder. We usually avoid this by moving the head when looking sideways, keeping the eyes fixed in relation to the centre of the lens. We know, provided the deviation of rays is small, that they cut the axis in a point, but that the greater the deviation, the greater the aberration. We must, therefore, confine the deviation produced at each surface of the lens within the narrowest possible limits, and this may best be done when the rays are deviated by the same amount at the two surfaces of the lens : we therefore arrange our lens so that rays of light enter one surface of the lens at an angle equal to that at which they emerge from the other surface (Fig. 162). The convex surface should face towards the incident rays, since they are more nearly parallel to the axis.

We should also endeavour so to arrange the lenses in the two eyes that the cylinders have approximately the same

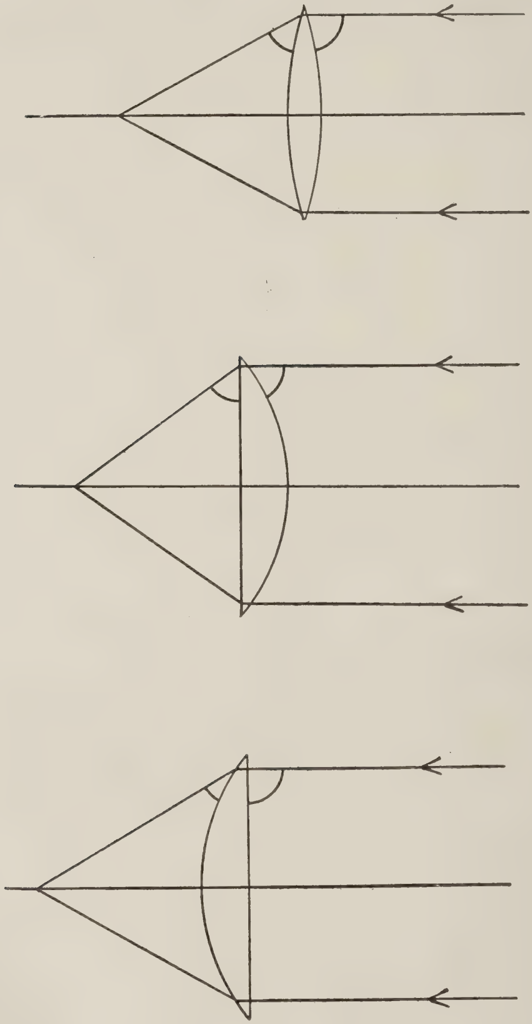


Fig. 162.

inclination, that is, both vertical or horizontal, and the same sign.

The rule for transposition of cylinders is as follows :—

The sphere will be the algebraic sum of the old spherical and cylindrical powers, combined with a new cylinder of equal strength to the old, but of opposite sign, and having its axis at right angles to that of the old.

Thus :	– 3·00 D sph.
	+ 2·00 D cyl. *ax.* 180°
becomes :	– 1·00 D sph.
	– 2·00 D cyl. *ax.* 90°.

CHAPTER VII

THE FUNCTION OF CONVERGENCE. MUSCULAR ANOMALIES

Convergence.—When an emmetropic person gazes at a far distant object the two visual axes are parallel, and in some the visual axes actually diverge, so that, produced backwards, they will meet behind the eyes. If, on the other hand, a near object is observed, then the two visual axes converge on that object, and, at the same time, there is an act of accommodation, so that a sharp image of the object is formed upon the macula of each eye. When the two visual axes do not meet at the object of gaze, then single vision is lost, and diplopia appears, owing to the two images falling upon disparate points of the two retinas. The two maculæ being identical points, single vision will result only when the visual axes meet at the object of regard.

Convergence is brought about by the simultaneous and equal contraction of the internal rectus muscles, and much of the comfort experienced when the eyes are used at short ranges depends upon the proper working of the act of convergence, be it a proper relation between accommodation and convergence, or a sufficiency in the power of converging the visual axes.

If we observe the eyes fixing a distant object, we notice that the visual axes of the eyes appear to us to be parallel. If now a prism, base out, be placed before one of the eyes, this eye will converge to overcome the displacement of the image produced by the prism, and so as to retain single vision, whereas the other eye continues to fix the distant object : it would thus appear as if the convergence were wholly undertaken by one eye only, the visual axis of the other eye retaining its original direction. Actually both eyes converge an equal amount, and then, in the condition of converged axes, both eyes

rotate through an angle equal to that of the convergence of one eye, so that one eye appears to fix, and the other appears to converge double that amount.

The Measurement of Convergence.—The *near point of convergence* is the nearest point for which the eyes can be converged without producing diplopia.

The *far point of convergence* is the point where the visual axes meet when the converging muscles are completely relaxed, and may be at infinity, at a distance less than infinity, at a distance greater than infinity; that is, the visual axes may be parallel, may converge, or may actually diverge when the muscles are completely relaxed.

The distance between the near point and far point of convergence is the *range of convergence*.

That part of the range of convergence between the near point and infinity is spoken of as *positive*, and that part beyond infinity as *negative*.

In divergent strabismus there is necessarily a large amount of negative convergence, whereas in convergent strabismus all the convergence is positive.

The near point of convergence is found by bringing a small bright object up towards the eyes, in the middle line, until diplopia is produced. Theoretically its distance should be measured from the *base line*, the line joining the centres of rotation of the two eyes. Clinically the distance is measured from the anterior principal focus, which is about 25 mm. in front of this line. This amount must therefore be added to the distance measured.

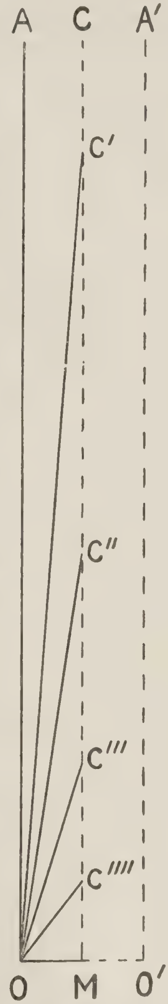


FIG. 163.—Metre Angle (Landolt).

The *amplitude of convergence* may be measured in various

ways, namely, by the angular displacement of the visual axes expressed in degrees, minutes, and so on, or by the strength of prism that an eye can overcome, positive convergence being measured by prisms base out, and negative by prisms base in.

The angular displacement of the visual axes will necessarily vary with the length of the base line; those with a long base line will require to converge the axes more than those with a shorter base line when viewing an object at the same distance from the eyes. For this reason Nagel has introduced a unit called the *metre angle.*

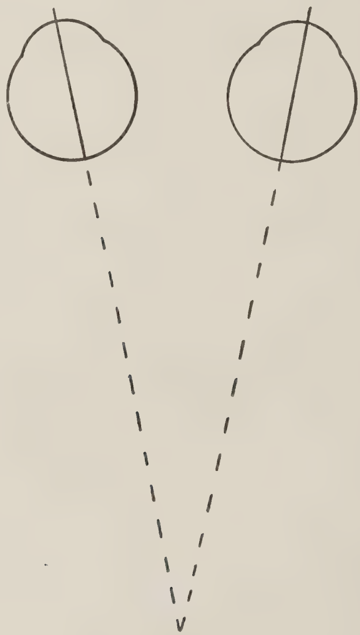


FIG. 164.—Divergence of the visual axes, which meet when produced backwards.

Let OO′ (Fig. 163) be the base line, that is, the distance between the centres of rotation of the two eyes; bisect this line at M. Draw MC at right angles to OO′, so that an object upon this line

viewed by the two eyes will produce equal convergence. Draw OA, O′A′, the visual axes of the two eyes, which are parallel in direction when the eyes are fixing an object at infinite distance. Let C′ be a point on the line MC at a distance of 1 metre from the eyes; the angle AOC′ is the angle through which the visual axis is turned to fix this object, and is termed the *metre angle.*

The angle OC′M is equal to the angle AOC′, since AO is parallel to C′M. In the triangle OC′M, $\frac{OM}{OC'}$ is the sine of the angle OC′M.

This will vary with the base line. Thus if the base line be 64 mm., then OM = 32 mm., and $\frac{OM}{OC'} = \frac{32}{1{,}000} = \cdot 032$ = sine of the metre angle, and from the trigonometrical tables the metre angle in this case is 1°50′.

When the eyes fix a point C″ at a distance of 50 cm. or 0·5 m., then each visual axis will converge through 2 metre angles. Again, $\frac{OM}{OC''} = \sin OC''M = \frac{32}{500} = \cdot 064$, and from the tables this is found to be the sine of an angle of 3°50′.

We see that convergence becomes greater as the point of fixation approaches the eyes. At the ordinary reading distance of 25 cm., 4 metre angles of convergence are exerted.

In measuring convergence with prisms, the positive portion is measured by the strongest prism base outwards that can be borne by the eyes whilst fixing a distant object without producing diplopia. With prisms gradually applied this amounts to 30° *d*. The negative portion of convergence is measured by the strongest prism base inwards that can be borne by the eyes whilst fixing a distant object without producing diplopia. This amount varies between 1·5°*d* and 4°*d*, but in any event is very much smaller in amount than the positive portion of convergence.

Relation between Accommodation and Convergence.—The

introduction of the unit metre angle has made it easy to correlate clinically accommodation and convergence ; an emmetropic eye accommodated for an object at a distance of 1 metre uses 1 metre angle of convergence and 1 D of accommodation, and so on.

Although this relation between the two functions exists, there is, nevertheless, a good deal of independence between the two, which will easily be appreciated when we consider the relation of accommodation to convergence in hypermetropia and myopia. In uncorrected hypermetropia, accommodation is always in excess of convergence, whereas in myopia convergence is always in excess of accommodation. We shall see that, in certain instances, a proper relation between accommodation and convergence, so as to preserve single vision, is so difficult to maintain, that a permanent deviation of the eyes is established, a condition known as strabismus.

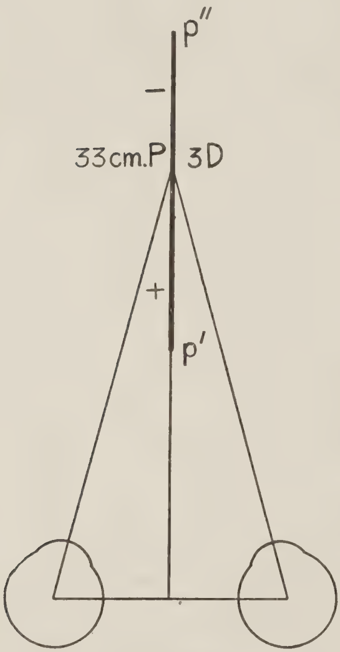


Fig. 165.

Relative Accommodation. — This is the amount of accommodation which it is possible to exert or relax for a given amount of convergence.

Let the eyes be accommodated for a point P, and at the same time let the eyes be converged to this point so that the amount of accommodation exerted is 3 D, and the convergence equals 3 M.A ; that is, the object is 33 cm. distant, and the eyes are emmetropic (Fig. 165). It will be found that we may place concave lenses of gradually increasing strength before the eyes, thus causing the individual to use more and more accommodation, and yet the same amount of convergence will be exerted

all the time, so that single vision is maintained all the while, the object remaining at a distance of 33 cm. The strongest concave glass that can be tolerated in these circumstances without producing diplopia represents the increase of accommodation possible, and is the *positive* amount of relative accommodation. Its range may be represented by the line Pp'. Thus the eye is accommodated for p', but converged for P.

In a similar way, whilst the eye is still converged for P, convex glasses of gradually increasing strength may be placed before the eyes, and the eyes will gradually relax a portion of the exerted accommodation up to a certain point, and still maintain single vision. The highest convex glass tolerated is the measure of the negative amount of the relative accommodation. In this way the eye may be accommodated for p'', but converged for P, and Pp'' represents the negative part of the range of relative accommodation.

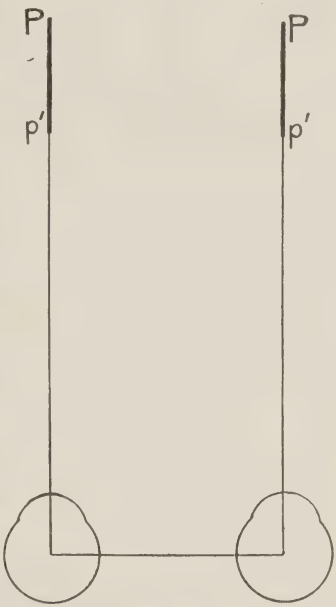


Fig. 166.

The total range of relative accommodation is, therefore, the sum of the positive and negative portions, and is represented by the distance $p'p''$.

The total range of relative accommodation will vary for each degree of convergence, as will be seen if we take two examples.

Let the eyes be emmetropic, with a good amplitude of accommodation.

Take as the first example the eyes fixing a far distant object, one of the lines of smaller letters of the test type, which an emmetrope will readily read. It will be found that these letters can also be read when $-$ 3 00 D is placed before each eye ; which means that the individual has added $+$ 3·00 D to

his intraocular lens, in other words, has accommodated 3 dioptres; he still retains single vision, and we will imagine that this is the limit of the concave lens he can overcome and retain single vision.

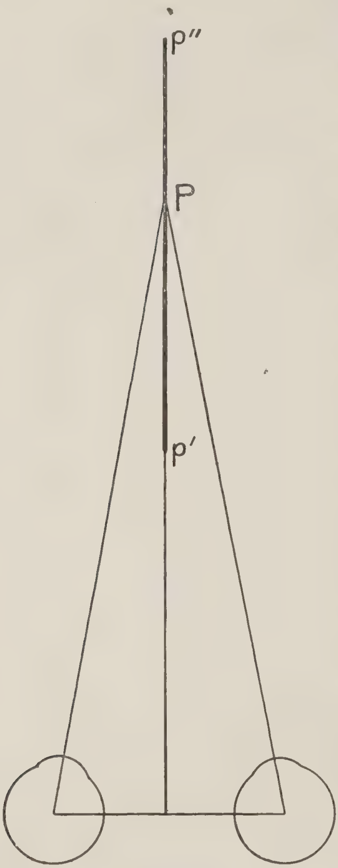


Fig. 167.

Thus he has exerted 3 dioptres of positive relative accommodation, which in the diagram is represented by the lines Pp', which also represents the total relative accommodation, since, the eye being emmetropic, there can be no negative portion with the eye focussed for infinity. Not even the lowest convex glass can be tolerated and good vision obtained.

Suppose now an object be placed at the distance of 1 metre from the eye. We shall find that the positive amount of relative accommodation is 3 D, that is, good vision, without diplopia, can be obtained with a − 3 D before each eye, the eye being accommodated for 33 cm., and converged for 1 metre.

We shall also find by placing + 0·5 D before each eye that he will relax his accommodation to that amount, that is, 0·5 D sph. represents the negative amount of the relative accommodation.

With the convergence arranged for nearer and nearer points, the positive portion of the relative accommodation becomes less and less, whereas the negative portion increases, and when the eye is converged to, say, 12 cm., no concave glass can be tolerated, since it requires all the accommodative effort possible

to see an object held so near. This point is the nearest point of relative accommodation, and the strongest convex glass with which distinct vision can be maintained is the measure of the amount of accommodation that can be relaxed whilst still fixing the point, and it thus represents the limit of the negative portion of the relative accommodation. If the object be brought nearer than this point the individual will require a convex glass to see an object clearly whilst maintaining the necessary convergence.

As the point of accommodation approaches the eye nearer and nearer, so does the line expressing the range of relative accommodation become shorter and shorter, and when no convex lens of higher dioptric value will be accepted than that which gives sharp vision, we know that no part of the exerted accommodation can be relaxed at all, and there is no negative range of relative accommodation with that amount of convergence.

Relative accommodation may be plotted in the form of curves on the ordinary system of co-ordinates as was originally done by Donders.

In the chart on p. 234 the figures along the horizontal line to the right indicate the metre angles of convergence exerted, and so 0 indicates parallelism, and 3 indicates 3 metre angles of convergence for a point $\frac{1}{3}$ metre or 33 cm. distant.

Negative convergence would be represented by an extension of the chart to the left.

The figures on the vertical line represent in dioptres the amount of accommodation exerted, and are, therefore, the reciprocals of the distance for which the accommodation is exerted : thus 0 represents the accommodation exerted for infinite distance, 3 that exerted for an object $\frac{1}{3}$ metre distant, that is, 33 cm.

In the chart the oblique line represents accommodation and convergence when they are equal; thus taking the figure 3 on the horizontal line, representing metre angles of convergence, and 3 on the vertical line, representing dioptres of accommodation, the point at which the two lines starting from these figures

meet is the point through which the oblique line passes, and so on. This line, therefore, represents both accommodation and convergence.

We plot the positive part of the relative accommodation above the diagonal and the negative part below.

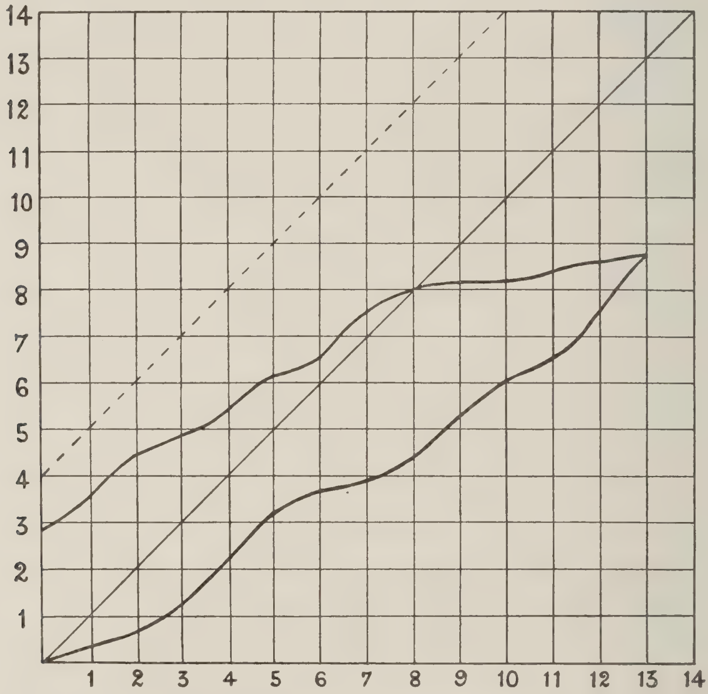


FIG. 168.—Relative Accommodation.

The individual from whom this chart was made was emmetropic and had no negative convergence. With the visual axes parallel he was able to exert 2·95 D of accommodation, and so, starting from the point of origin, we count upwards three squares and place a dot at the appropriate spot, and this figure will represent the total relative accommodation. Take now the case when the eyes converge 1 metre angle : it will be found that the positive part of the relative accommodation is 2·59, so, therefore, starting from the point where the diagonal line

crosses the first horizontal line, we count upwards, and make a mark in the appropriate position. It is found, also, that there is a negative portion of the relative accommodation of 0·72, and so from the point where the diagonal line crosses the first vertical line we count downwards, and make a mark about three-quarters of the first square. The total relative accommodation is, therefore, 3·31, the sum of the positive and negative portions.

As we proceed with each point of convergence, we shall see that the positive portion of the relative accommodation becomes less and less, whilst the negative portion increases, and a point is met when with 8 metre angles of convergence we have to deal only with the negative portion of the relative accommodation. At this point the individual is unable to overcome any concave lens, and can only relax 3·61 D of his accommodation. After that point is passed he will require a convex lens to see the object held before him, and thus the negative part of the relative accommodation has two portions until a point is reached, when 13 metre angles of convergence are exerted, at which there is no relative accommodation, a point where there is no range between the two convex glasses that may be placed before the eye.

As we have seen, this chart is that suitable for an emmetrope, but when we deal with ametropia, certain modifications are necessary. Take a case of myopia of 4 dioptres ; in this case the punctum remotum is at 25 cm., and thus the individual can see an object at this distance without accommodation, although exerting 4 metre angles of convergence, and with a convergence of 6 metre angles he would use but 2 dioptres of accommodation, and so on. In mapping the curve of relative accommodation on the chart, we must, therefore, begin the diagonal line, not from the point of origin, but from a point on the vertical line four squares below it, and then extend it as we did in emmetropia. In the case of hypermetropia, in which accommodation is always in excess of convergence, we shall begin the diagonal line (in the case of 4 dioptres of hypermetropia) on the vertical line four squares above the zero mark.

The range of relative accommodation necessarily varies with age, since, as we have seen, the amplitude of accommodation becomes less and less as age advances. Up to the age of twenty-five years the emmetrope is able to attain full distant vision when a lens of $-3{\cdot}25$ D sph. is placed before his eyes; after twenty-five years the concave lens that can be overcome gradually diminishes in strength until at sixty-five years no concave lens will allow full distant vision.

Clinically it is only necessary to measure the amount of relative accommodation with a convergence of 3 metre angles, that is, at a distance of 33 cm., the ordinary reading distance. Having rendered the eye emmetropic, if necessary, with suitable lenses, we give the patient a near type that should be read at 0·3 metre. It is important to measure the distance and ensure that the patient holds the type rigidly at 33 cm. We now place concave lenses before each eye, and record the strongest lens with which the patient can read the type readily. This is the measure of the positive part of the relative accommodation.

The importance of this observation was pointed out by Donders, who stated in his work, "the accommodation can be maintained only for a distance at which, in reference to the negative part, the positive part of the relative range of the accommodation is tolerably great." If, owing to the failure of the amplitude of accommodation, clear vision cannot be obtained at 33 cm., this deficiency must be supplemented by the addition of convex lenses, and in actual practice our endeavour, when prescribing glasses for presbyopia, is to keep the positive part of the relative accommodation "tolerably great."

Relative Range of Convergence.—We have seen when examining the relation between accommodation and convergence that a certain amount of convergence could be maintained with varying amounts of accommodation. In the same way we may find that with a certain degree of accommodation varying degrees of convergence may be maintained. The amount of convergence which can be exerted or relaxed

with a given degree of accommodation is called the *relative convergence.*

Let an individual accommodate for a certain distance. We shall find that whilst he retains a sharp image of that point, we are able to place prisms with their bases outwards before the eyes, and the strongest prism, base outwards, which can be overcome, is the measure of the positive portion of the relative convergence, and similarly, the strongest prism, base inwards, that can be tolerated is the measure of the negative part of the relative convergence.

In the diagram with the eyes accommodated for B, B*a* represents the positive part of the relative convergence, and B*b* the negative part. We may plot out the relative convergence in a similar way to that we made use of in plotting the relative accommodation. In this each one of the squares from below upwards represented 1 dioptre of accommodation, and each square from left to right represented 1 metre angle of convergence. *In plotting relative convergence we must count horizontally from the same point on the diagonal*, as only in this direction can convergence be measured, so many squares to the right representing the positive portion, and so many to the left representing the negative portion of the relative convergence. Comparing the two charts we see that positive relative accommodation is of the same character as negative relative convergence, and *vice versâ*, but the two charts do not coincide, since in plotting out relative convergence we find that the lines representing the positive and negative parts are more nearly parallel to the diagonal (Fig. 170).

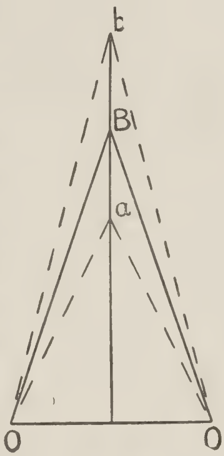


FIG. 169.

Strabismus.—Naturally the two eyes are so related in position one to the other that the two visual axes meet at the point of fixation. When this natural relation is absent a condition of *strabismus* or *squint* is said to occur.

For clinical purposes we divide strabismus into two groups, the first, those cases of which we know the cause, the second, those of which the cause is not actually known.

In the first group are cases of strabismus due to paralysis of one or more extraocular muscles, and called *paralytic strabismus*,

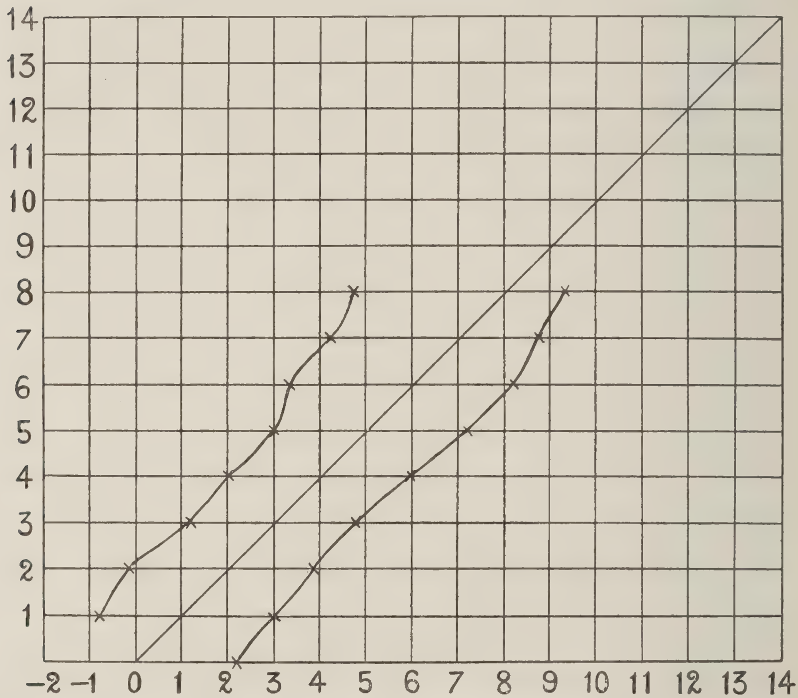


Fig. 170.—Relative Convergence.

and in the second, cases in which the visual axes are not directed to the same point in space, but which retain the same relative position of the visual axes in every movement of the eyes, and are, therefore, called cases of *concomitant strabismus*. Under this heading may be grouped cases in which the strabismus is only revealed by special tests, cases of *latent strabismus* or *heterophoria*.

It is mainly with the group concomitant and latent strabismus

that we have to deal in considering the refraction of the eye, but, so that the two groups of strabismus should be recognised, some description and consideration of paralytic strabismus is necessary.

Paralytic Strabismus : Signs and Symptoms.—1. *Limitation of Movement.*—The loss of power of a particular muscle will impair the ability of the eye to be moved in some cardinal direction, that is, up, down, in or out, the direction in which the paralysed muscle normally moves the eye. If this loss of power be slight, an inspection will perhaps not be sufficient to decide which muscle is affected, as the slight loss of power may not be apparent, and the lagging of the affected eye not sufficiently gross to be obvious. The eyes move normally outwards 50°, inwards 50°, upwards 33° and downwards 50°. The test is carried out by fixing the patient's head, and asking him to follow with his eyes the movements of the finger in the cardinal directions mentioned above. When the eyes look in the direction in which the paralysed muscle would move the eye, if acting normally, the affected eye will fail to move, or, at any rate, fail to move throughout its normal angular excursion : the deviation of the

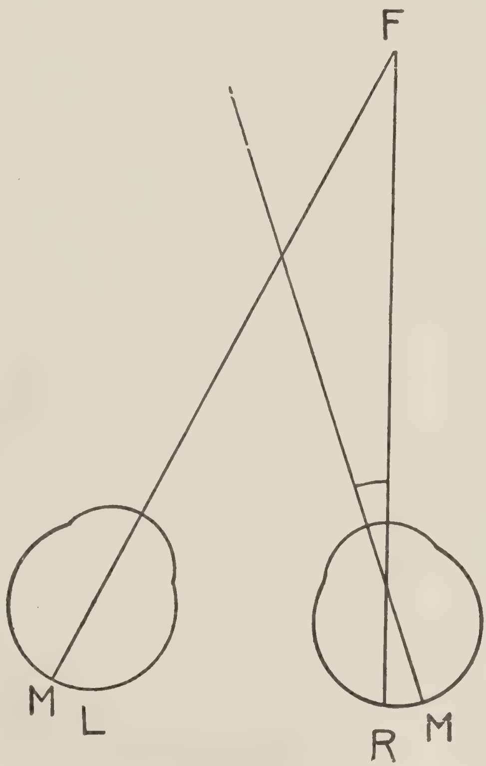


Fig. 171.

eye is in a direction opposite to the action of the muscle, and is known as the *primary deviation.* It is measured by the angle which a line from the object to the nodal point of the eye makes with the visual axis.

When fixation is assumed by the affected eye the same amount

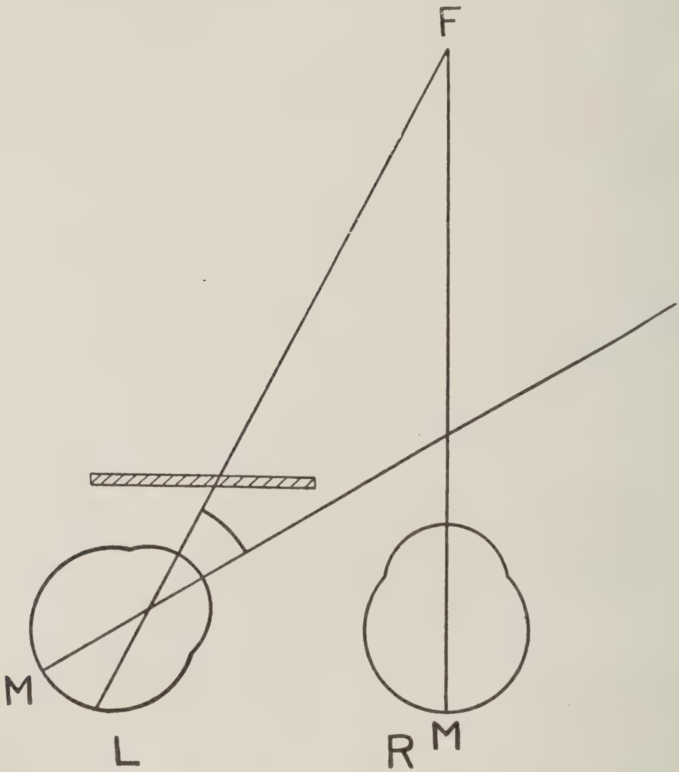


Fig. 172.—Test to show Secondary Deviation.

of nervous energy passes to the associated muscles of the two eyes, for instance, the right external rectus muscle and the left internal rectus muscle, and supposing the right external rectus muscle to be paralysed, an abnormally great impulse is required to stimulate it; as a result, the left internal

rectus muscle is over-stimulated, and its movement consequently excessive.

This so-called *secondary deviation* is greater than the primary deviation.

This is demonstrated as follows : whilst the patient is fixing some object about a foot from his face, the healthy eye is covered with a screen, when we shall find that the eye that is covered will deviate still more than the primary deviation of the paralysed eye (Fig. 172).

This difference in amount between the primary and secondary deviation is most important, as being a distinguishing feature between paralytic and concomitant strabismus.

2. *Diplopia or Loss of Binocular Single Vision.*—Patients come for relief, not because they notice any loss of movement of the eyes, but because they see double, which is due to the fact that the images in the two eyes do not fall upon "identical points" of the two retinæ ; this diplopia will be in that part of the field of fixation to which the paralysed muscle normally moves the eye.

In the healthy eye the image will fall upon the macula, and be, consequently, bright and distinct ; in the affected eye the image will fall upon some portion of the retina outside the macula, and so will be indistinct and blurred, and we shall see that this so-called *false image* is projected into space in relation to the *true image* in the same cardinal direction as the healthy muscle would move the eye.

3. *False Orientation of the Field of Vision.*—This is due to a false impression of the position of an object in that part of the field of vision towards which it requires an effort on the part of the affected muscle to turn the eye. Taking the case of a patient with paralysis of the right external rectus muscle : upon asking him (with the left eye occluded) to fix an object well to his right-hand side and then suddenly touch it with his finger, he will strike wide of the object to the right-hand side. The explanation of this phenomenon is that of the increase of the secondary deviation, in that an object is projected according to the amount of nervous energy put forth in moving the eye to

fix it, and since, with a paralysed muscle, the amount of energy is in excess of the normal, the object is projected too far in the direction of action of the paralysed muscle.

4. *Vertigo.*—This is an occasional symptom of paralytic strabismus when both eyes are open, and depends upon two factors, the first a confusion due to the diplopia, and the second, false orientation. When the eyes are directed from the position in which the orientation is correct to that in which it is false, objects appear to move more or less rapidly in the direction in which the eyes are moving, producing an effect as if the patient were spinning on his feet.

5. *Altered Position of the Head.*—So as to overcome diplopia, the patient holds his head so that he turns his face in the direction of action of the paralysed muscle, the effect upon the affected eye being that the head turns the eye in the direction in which the paralysed muscle would turn it when in health. In the case of paralysis of the right external rectus, the face will be turned to the right.

The Investigation of a Case of Paralytic Strabismus and the Diagnostic Value of Diplopia.—When a patient complains of diplopia we must first be satisfied that the diplopia is not monocular, a condition seen in certain cases of astigmatism and of opacities in the lens.

We have already spoken of certain directions in which the eyes are moved as being *cardinal*, that is, up, down, in, out, and when we consider the various extraocular muscles, we see that each of them moves the eye mainly in one of these directions, and we can, by turning the eyes in various directions, cause the various muscles to act mainly as lateral turners, as elevators or depressors.

The external and internal recti act purely in the horizontal direction, and the superior and inferior recti can be made into almost pure elevators and depressors by causing the eyes to turn 27° outwards before they are brought into play. Again, by turning the eyes inwards, the superior and inferior oblique muscles can be made into almost pure elevators and depressors: thus we are able to resolve diplopia into *horizontal* or *vertical*.

When the images are separated laterally, so that the right image belongs to the right eye and the left to the left eye, the diplopia is spoken of as *homonymous*, but if the left image

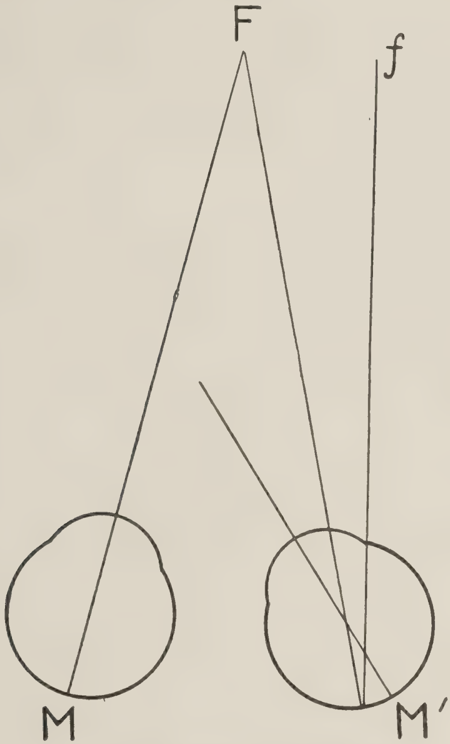


FIG. 173.—Paralysis of an Abductor.

belongs to the right eye, and the right to the left, it is called *heteronymous*, or *crossed diplopia.*

The Production of Homonymous Diplopia.—If the right eye turns inwards, convergent strabismus, the image falls upon a point of the retina internal to the macula. It is, therefore, projected to the right in the direction *f*, so that *convergent strabismus* produces *homonymous diplopia* (Fig. 173).

The Production of Heteronymous or Crossed Diplopia.—If the right eye turns outwards, the image of the object falls on a point

of the retina outside the macula. It is, therefore, projected to the left, to position *f*, so that a *divergent strabismus* produces a *crossed diplopia.*

Therefore paralysis of an abductor muscle produces homony-

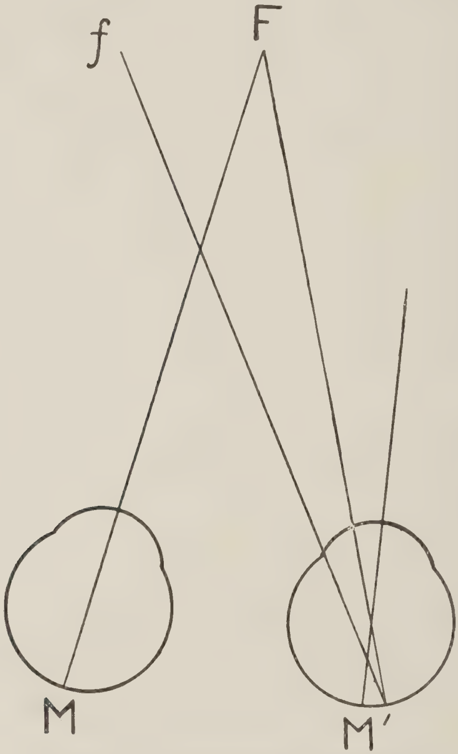


Fig. 174.—Paralysis of an Adductor.

mous diplopia, whilst paralysis of an adductor produces crossed diplopia.

In a similar way with paralysis of an elevator muscle, the false image lies on a higher level than the true image; in paralysis of a depressor muscle, the false image lies below the true image.

The diplopia will increase the more the eyes are moved in the

direction of the physiological action of the paralysed muscle, and it is by finding the direction of maximum diplopia that the particular muscle involved is recognised.

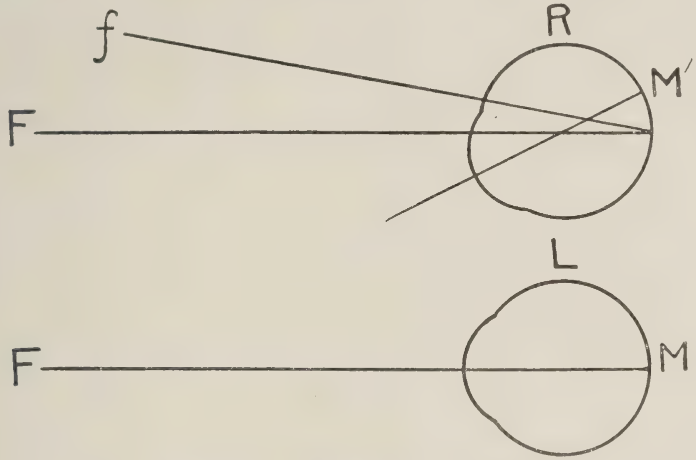


Fig. 175.—Paralysis of an Elevator.

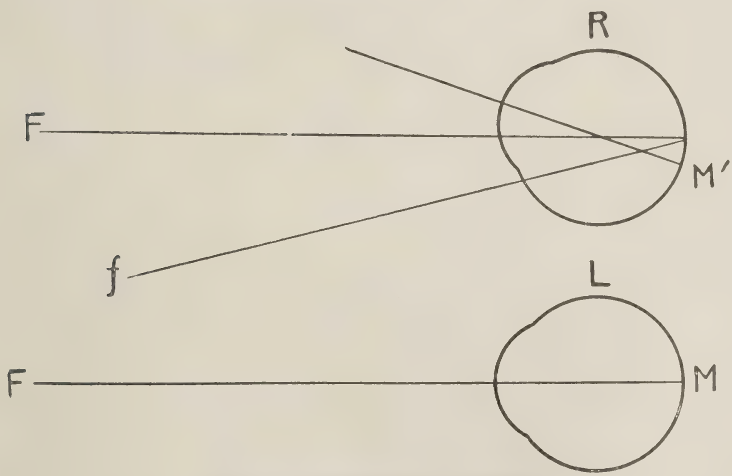


Fig. 176.—Paralysis of a Depressor.

Actions of the Muscles.—The external and internal recti muscles act in a horizontal direction, and, as a consequence,

the maximum diplopia is produced when the eyes turn in a horizontal direction towards the paralysed muscle.

The superior and inferior recti muscles become pure elevators and depressors (without adduction or torsion) when turned 27° outwards, and so maximum vertical diplopia is produced when looking up and out or down and out respectively.

The inferior oblique and superior oblique muscles become simple elevators and depressors when the eyes are turned strongly inwards, and maximum vertical diplopia is produced when looking up and in and down and in respectively.

Muscles may be grouped into a series of six pairs, each pair consisting of " true associates."

1. *Muscles moving the eye laterally.*
   - (*a*) To the right :
     - Right external rectus.
     - Left internal rectus.
   - (*b*) To the left :
     - Left external rectus.
     - Right internal rectus.
2. *Muscles moving the eyes upwards.*
   - (*a*) With the eyes turned to the right :
     - Right superior rectus.
     - Left inferior oblique.
   - (*b*) With the eyes turned to the left :
     - Left superior rectus.
     - Right inferior oblique.
3. *Muscles moving the eyes downwards.*
   - (*a*) With the eyes turned to the right :
     - Right inferior rectus.
     - Left superior oblique.
   - (*b*) With the eyes turned to the left :
     - Left inferior rectus.
     - Right superior oblique.

To Find the Direction of Maximum Diplopia.—A dark room is essential, about 15 feet long. A red glass is held before the right eye, and a green before the left, so that the images

belonging to the two eyes may be readily recognised. The head is kept stationary, and a lighted candle is moved about the binocular field of fixation. The positions of the images are marked upon a chart such as this :

THE PATIENT LOOKS

Upwards to the Left. LEFT SUPERIOR AREA.	*Upwards.* SUPERIOR MEDIAN AREA.	*Upwards to the Right.* RIGHT SUPERIOR AREA.
To the Left. LEFT EXTERNAL AREA.	*Straight ahead.* PRIMARY AREA.	*To the Right.* RIGHT EXTERNAL AREA.
Downwards to the Left. LEFT INFERIOR AREA.	*Downwards.* INFERIOR MEDIAN AREA.	*Downwards to the Right.* RIGHT INFERIOR AREA.

FIG. 177 (Maddox).

If, for instance, maximum diplopia occurs when the patient looks upwards and to the right, the condition must be due to paralysis of the right superior rectus muscle or the left inferior oblique muscle, and since we only consider the diplopia in the cardinal directions, any error that might be introduced by a pre-existing heterophoria is eliminated.

It remains now to distinguish which is the affected eye ; if upon covering the right eye the higher image disappears, the right superior rectus muscle is paralysed, whilst if the higher image disappears when the left eye is covered, then the left inferior oblique is the muscle at fault (Figs. 175, 176).

Concomitant Strabismus.—This is the form of strabismus more commonly met with, and from the point of view of refrac-

tion, is the more important, as we shall see that the refraction of the eye has considerable bearing upon the origin of strabismus. The peculiarity of concomitant strabismus is that the squinting eye is able to follow the movements of the other eye in all directions, the angle of strabismus remaining the same size.

We saw in speaking of paralytic strabismus that the secondary deviation was always greater than the primary, and we also saw how the test was applied. The same test applied to a case of concomitant strabismus shows that the secondary deviation is always equal to the primary deviation, and this test is most important in distinguishing these groups of strabismus.

Apparent Strabismus.—There are two conditions that give the appearance of strabismus when none exists.

The optic and visual axes rarely coincide. The optic axis, that is, the axis upon which the refractive media of the eye are centred, passes approximately through the centre of the pupil, and so through the centre of rotation of the eye, whereas the visual axis joining the point of fixation and the macula, cuts the optic axis at the nodal point so as to make a small angle. If this angle is well marked, as in cases of high hypermetropia and myopia, the appearance of strabismus is simulated. The matter has been discussed in considering the angle α, and when the optic axis cuts the cornea to the temporal side of the visual axis, the angle α is said to be positive, and a condition of divergent strabismus is simulated, whereas when the optic axis cuts the cornea to the nasal side of the visual axis the angle α is said to be negative, and the condition of convergent strabismus appears.

The second condition producing apparent strabismus is when the eye is not placed in the palpebral fissure midway between the internal and external canthi. Such a state is most markedly seen in cases of epicanthus, when a fold of skin passes from the inner end of the eyebrow to the side of the nose, covering the internal canthus. Both the eyes now appear to be nearer the inner end of the palpebral fissure than the outer, and if one eye be moved so as to place it in the middle of the

palpebral fissure, the other eye, following it, will appear to be partly covered by the inner canthus, and the condition of convergent strabismus will be closely simulated.

Varieties of Concomitant Strabismus.—These are named according to the deviation of the squinting eye :

Strabismus convergens, when the eye deviates in.

Strabismus divergens, when the eye deviates out.

Strabismus sursum vergens, when the eye deviates upwards.

Strabismus deorsum vergens, when the eye deviates downwards.

The commonest form of concomitant strabismus is convergent, the next divergent, whereas vertical deviations are comparatively rare.

Convergent strabismus is usually associated with hypermetropia, and divergent with myopia.

The squint may be *periodic* or *constant*, and, if constant, either *monocular*, that is, the same eye usually deviates whilst the other fixes, or *alternating*, when either eye fixes indifferently.

In monocular squint, the squinting eye nearly always has a higher error of refraction than the other eye, and, partly owing to this, the vision in the squinting eye is always poor. In alternating strabismus the vision in the two eyes is equally good.

When a case of strabismus presents itself, our first duty is to find out the type of case, whether paralytic or concomitant, at the same time ruling out the cases of apparent squint.

The tests for paralytic strabismus have already been mentioned, so that, having eliminated paralysis, we can apply further tests for proving that the case is one of concomitant strabismus. Ask the patient to fix the finger which is held about 3 feet from his face ; cover the right eye, the left eye will now fix the finger, and then rapidly cover the left eye, uncovering the right. If the right eye move in any direction so as to take up fixation, then there is a true strabismus, as the right eye must have been looking in some direction other than that of the finger whilst it was covered. In this way we may eliminate paralytic and apparent strabismus, since in the latter condition the eyes will remain quite motionless

during the test. That the secondary deviation is equal to the primary can easily be proved by covering the eyes alternately, and noting the deviation of the screened eye. The power of movement of the eyes in various directions should be examined, as some deficiency in the power of moving an eye outwards that has a convergent squint is not infrequently seen.

Diplopia is always a symptom of paralytic strabismus (provided the visual acuity be sufficient), whereas in concomitant squint it is practically never present. This is due to suppression of the image in the squinting eye. A high degree of ametropia when present assists in the suppression of the image in the squinting eye.

Concomitant strabismus always begins in early childhood, over 70 per cent. before the fifth year, and the greater majority before three years of age.

Causes of Concomitant Strabismus.—The cause of concomitant strabismus is not a settled matter. Nevertheless, so that a rational treatment may be undertaken, some hypothesis must be formulated to act as a foundation.

1. *A lack of co-ordination between accommodation and convergence.* The first step in pointing to a method of treatment of concomitant strabismus was an observation by Donders, that convergent strabismus was often associated with hypermetropia.

We have seen that there is a very definite relation between convergence and accommodation.

Take a pair of emmetropic eyes and a point of fixation in the middle line at a distance of 1 metre. To see this object clearly requires an effort of accommodation of 1 dioptre, that is, the ciliary muscles must, by their contraction, add the equivalent of 1 dioptre to the crystalline lenses. The eyes have also to make a movement of convergence, and the angle through which each eye moves is known as a metre angle. Thus the impulse associating convergence and accommodation for an object at a distance of 1 metre produces 1 dioptre of accommodation and 1 metre angle of convergence ; at half a metre, 2 dioptres of accommodation and 2 metre angles, and so on in a constant ratio.

Now, in the case of hypermetropia, the patient has, first of all, to correct his hypermetropia by an effort of accommodation, and, if he fixes an object at a distance of 1 metre, to add yet another dioptre to the crystalline lens, so that if he have 4 dioptres of hypermetropia, he will have to exert 5 dioptres of accommodative effort to 1 metre angle of convergence, and, as it were, suppress 4 metre angles of convergence. Apart from any other consideration, the maintenance of so much accommodative effort is very fatiguing, and when associated with a further effort to prevent too much convergence, may lead to a breakdown in the preservation of accurate accommodation, or in the maintenance of a suitable convergence of the visual axes. The result may be that the patient converges for a point nearer to him than that for which he accommodates, thus producing a convergent strabismus.

A consideration of this argument will show how important it is to correct fully any hypermetropia present in cases of convergent concomitant strabismus.

A similar explanation connects myopia with divergent concomitant strabismus, as there is a want of balance between the efforts of accommodation and convergence. Take, for instance, a myope of 10 dioptres, whose punctum remotum is therefore 10 cm. from his eyes : he will require 10 metre angles of convergence to see an object at such a distance with the accommodation in a state of rest. This puts a great strain upon the convergence, and the result is that the patient converges for a point farther from him than the point for which the eyes are accommodated, thus producing a divergent strabismus. Again we see the importance of correcting myopia in cases of divergent strabismus.

2. *Any condition, such as anisometropia, amblyopia, opacities in the media, and so on, that causes the visual acuity of one eye to be below that of the other.* In such circumstances the necessity of accurate convergence to produce single vision is absent, and so there is developed a convergent or divergent strabismus. We thus see that our efforts, especially in cases of amblyopia, are required, not only to correct the error of refraction, but to

improve the vision of the eye of less acuity so that the stimulus of diplopia may cause proper convergence.

3. *Defect of the fusion faculty and of innervation.* When an object is observed so that the images fall upon the macula of each eye, that object appears single, owing to a cerebral process whereby the two retinal images are fused into one, so called binocular single vision.

This power varies with different individuals, being more developed in some than others, so that whereas some can so combine the slightly different retinal images as to produce a form of relief spoken of as stereoscopic vision, others have merely simultaneous vision in each eye without its being stereoscopic.

It is suggested that when this power of fusion is poorly developed anything that upsets the balance of action of the extraocular muscles, which preserves the normal relative position of the eyes, will cause a concomitant strabismus. Such a factor may be found in an error of refraction or some acute illness, such as whooping cough.

Hence we see that after an error of refraction has been corrected and the vision of an amblyopic eye restored, still there remains the necessity of developing the fusion faculty by some form of binocular exercise.

Measurement of the Angle of Squint.—The tangent scale of Maddox, introduced for use with the glass rod test for hyperphoria, is well adapted for the measurement of the angle of squint. The test is carried out at the distance of a metre, the small figures on the scale representing the tangents of angles subtended at that distance.

The patient is seated in front of the light at the zero mark on the scale, holding a tape or stick, 1 metre long, against the cheek, the other end of the measure being fixed to the scale.

The surgeon faces the patient with his head just below the level of the light, and about 30 cm. from the patient. He directs the patient to look at various numbers on the scale until the reflex of the light is seen in the middle of the cornea of the squinting eye. He now knows that the sound eye is deviating an amount equal to the deviation of the squinting eye when the

sound eye was fixing the light. The figure at which the patient is gazing gives the angle of deviation.

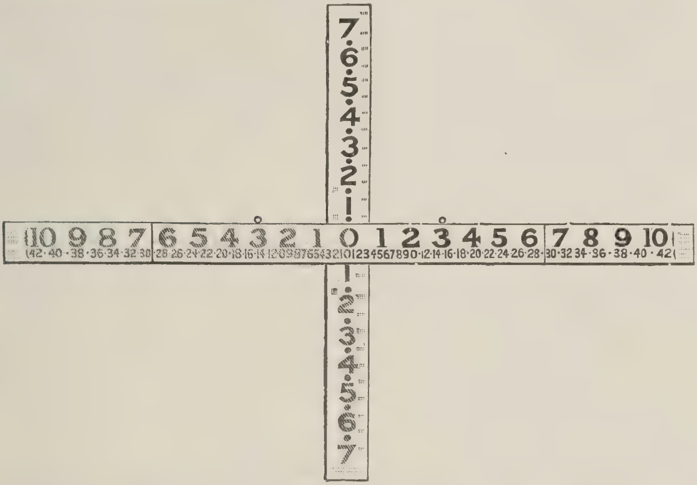


FIG. 178.—The large figures indicate tangents of degrees at distance of 5 metres. A light is placed at the centre of the cross. The position of the light streak seen through the rods indicates the deviation of the eyes. The small figures are used in the objective measurement of squint at 1 metre. The figures shaded in the illustration are red on the scale.

This reading may be supplemented by testing for concomitancy, the angle of squint being measured with the patient's face turned to one side or the other, when the deviation should be the same in all positions. The secondary deviation may also be measured by covering the sound eye and asking the patient to fix the number that measures the angle of the squint. Upon suddenly removing the screen, the reflex in this eye should be in the middle of the cornea.

Before measuring the angle of a squint the angle *kappa* should be measured, as has been described elsewhere, and the amount taken into consideration when measuring the angle of the squint.

A rough estimate of the angle of squint can be obtained in the dark room by observing the position of the corneal reflex in the squinting eye, caused by reflecting light into the eye with an ophthalmoscopic mirror. If the reflex occupies the

margin of the medium pupil, there are 15° of squint, whilst with the reflex at the margin of the cornea there is a squint of 45°.

Treatment of Infantile Strabismus.—Only a short outline of the methods adopted can be given here.

1. We have seen the frequent relation between convergent concomitant strabismus and hypermetropia, and between divergent strabismus and myopia. Consequently, it is of the greatest importance to correct with glasses any error of refraction.

The accommodation is thoroughly paralysed by the use of atropine applied to the eye thrice daily for at least three days. At the end of that time the refraction of the eye is determined by retinoscopy.

Lenses that correct the whole of the astigmatism and all but 1 D of the hypermetropia are ordered for constant use, and the use of the atropine is continued for the first week that the glasses are used, but no longer.

2. If the vision of the squinting eye is below 6/36, continuous occlusion of the fixing eye for several weeks, followed by occlusion for half to one hour three or four times daily.

3. The instillation of atropine into the fixing eye once daily. By this means the patient uses the fixing eye for distant vision, and the squinting eye for near vision.

4. When the vision in the squinting eye is so far improved that the child can alternate, it is advisable to attempt a cultivation of binocular vision by orthoptic exercises.

In children under six years of age these exercises are carried out with some form of stereoscope with simple pictures in the first instance, followed by carefully graded exercises with pictures which are more difficult to fuse.

5. For cases in which the deviation is not overcome by the means mentioned above, the deformity may be corrected by operation.

Heterophoria.—We have seen that in strabismus there is a deviation of the two visual axes which is manifest. Besides manifest squints, there are certain latent deviations which may be made manifest by special tests which dissociate the two eyes.

A latent squint is prevented from becoming a manifest squint by the effort so to regulate the deviation of the visual axes that single vision is maintained. If now, instead of allowing the eyes to fix one object, we produce an artificial diplopia, so as to render fusion of the two images impossible, or cause the two eyes to fix two different objects at the same point in space, then any tendency to squint will become manifest, and we shall be able to study the direction in which the deviation takes place. This is called "dissociation of the eyes," and may be brought about by various methods, the one most commonly used being that in which one eye fixes an object, usually a point of light, and before the other eye is placed a device which so alters the appearance of the point of light that the images in the two eyes cannot be fused.

There is a well-known co-ordination between the functions of accommodation and convergence, and we have seen that for each dioptre of accommodation there is a movement inwards of each eye through 1 metre angle. Although this relation is intimate, it will be found that the experiment of dissociating the two eyes during fixation of a distant point will show a tendency on the part of the eye which is partially occluded to deviate inwards or outwards to a slight degree. If the object be brought gradually from a distant point to a nearer one, the convergence does not keep pace with the accommodation, so that the partially occluded eye will have deviated outwards through 3° or 4° ; this condition is physiological, and will be present in the great majority of individuals without producing any symptoms. It is only when this deviation is of a high degree that symptoms are produced, and in some a temporary manifest squint is produced when the individual is fatigued.

Orthophoria is the term applied to perfect muscle balance. *Heterophoria* is the term applied to all conditions of latent deviation, produced by tests which render single binocular vision impossible. The deviation may be in a variety of directions, upwards, downwards, inwards, outwards, or in some intermediate direction, which we resolve into its two elements,

each of which is described separately; thus latent deviation up and out is resolved into so many degrees upwards and so many outwards.

We have considerable control over our power of convergence of the visual axes, and also to a less degree over our power of divergence; we have, however, practically no power of elevating or depressing the two eyes independently, and it is as a result of this that latent deviations in the vertical meridian cause more symptoms than those in the horizontal meridian, and are, therefore, of much greater importance. Latent divergence is spoken of as *exophoria*, latent convergence as *esophoria*, latent vertical deviation as *hyperphoria*.

One of the early tests was to make an individual fix a point of light, or a dot on a card, and to place before one eye a prism, base up or down, so that the object was doubled in a vertical direction; if now one image moved to one side of the other it was proved that the eye, in which that image was formed, had deviated in the horizontal direction. The amount of deviation was measured by the prism which, base out or in, brought the two dots one above the other.

The simplest and most rapidly performed test is that carried out with the Maddox rod and tangent scale.

The test depends upon the distortion produced when a point of light is seen through a strong cylinder, which makes the spot of light into a line of light. If this cylinder be held before one eye, say, with its axis horizontal, a vertical line of light will be seen by the eye, whereas the other eye sees the point of light in its natural condition; in this way the images are so different that the eyes are dissociated, and take up a position of rest.

The original apparatus consisted of a single rod of glass mounted before a stenopæic slit. In more recent models, however, it consists of a series of pieces of red glass rod arranged side by side over the opening in a disc of vulcanite, on which should be marked, with lines, the axes that are parallel to and at right angles to the rods.

The other portion of the apparatus consists of a vertical and

horizontal tangent scale, crossing each other at the zero mark. On the scales are marked in large figures the tangents of the angles subtended at the eye at a distance of 5 metres. (See Fig. 178.) The figures above and to the right of the zero mark are in black, those below and to the left in red. There is also printed along the horizontal scale a series of small figures representing the tangents of angles subtended at the eye at the distance of 1 metre. At the zero mark is a point of light, usually an electric bulb contained in a box, in front of which is a diaphragm, the aperture of which may be varied in size.

The patient is seated in front of this scale with his eyes on a level with the source of light and immediately opposite it; a trial frame is placed in position on his face with the glass rods before the right eye with their axes horizontal. The patient wears his correcting lenses, and care must be taken that the head is held upright, and that the patient looks quite normally through the glasses.

The patient is asked to state through which figure the red line of light passes. If, for instance, he says through the red figure 3, then we know that he has crossed diplopia, and, consequently, that the right eye has deviated outwards, and if a prism of 3° *d* be placed, base inwards, before the right eye, that the streak will probably pass through the source of light. It will be found, however, that horizontal deviations vary a good deal, and at one moment the red line will be projected to the red figure 3, and at another to 5, and so on.

A confirmation as to the correctness of the patient's statements is easily obtained by placing a 6° prism, base in, before the left eye, when the red streak, previously at the red 3, will now pass to the black 3.

The rods are now rotated so as to be at right angles to their previous position, the streak becoming horizontal in direction; we now ask the patient if the streak is above or below the light. In the great majority of patients the red streak will pass almost exactly through the source of light. If, however, it lies above the light, the right eye is deviated downwards, and if below, there is a deviation of the right eye upwards. When

speaking of hyperphoria we always indicate the eye that has moved upwards, so that if the red line is above the light there is left hyperphoria, and if below the light, right hyperphoria the deviation of the eye being in the opposite direction to that of its false image. Again, the figure through which the red line passes indicates the angle of deviation of the prism, which, suitably placed before the eye, will correct the deviation of the eye.

Now heterophoria may be paralytic, and, therefore, it must not be assumed that every case of heterophoria is concomitant, and care must be taken to prevent such a mistake. The test depends upon the fact that in concomitant squint the primary and secondary deviations are equal, whereas in paralytic squint the secondary deviation is always greater than the primary deviation; we therefore perform the test for heterophoria with the head in different positions.

The eyes should also be tested for heterophoria at 25 cm., and Maddox has designed an apparatus for this purpose, called the wing test for heterophoria. With lenses that correct both ametropia and presbyopia the apparatus is held before the eyes, and so that the patient's accommodation for 25 cm. should be ensured the patient should be asked to read the small print below the scale. The arrow points to the figure or letter that indicates the angular deviation of the prism that will correct the defect.

As in the distance test, when the apparatus is so arranged to discover hyperphoria, the arrow in the great proportion of cases passes through the zero, but it is usual to find exophoria that may be as high as 8°, and still be within physiological limits. In fact, it is difficult to fix the limit between physiological and pathological exophoria, and other factors must be taken into consideration in deciding the point, such as muscular asthenopia and the rest.

It is important to know, before we speak of the treatment of heterophoria how much power a given individual has of suppressing an artificially produced diplopia, and this power is spoken of as the "breadth of fusion."

In the case of hyperphoria the test is easily applied and is measured by finding the strongest prism, base up, and the strongest, base down, which can be held before an eye with hyperphoria without producing diplopia. Half the difference between the prisms is the measure of the true hyperphoria.

The test cannot easily be carried out in deciding the " horizontal breadth of fusion " in the same way, and a special device, the prism verger, has been introduced for this purpose ; it is an instrument that can also be used in measuring the " vertical breadth of fusion."

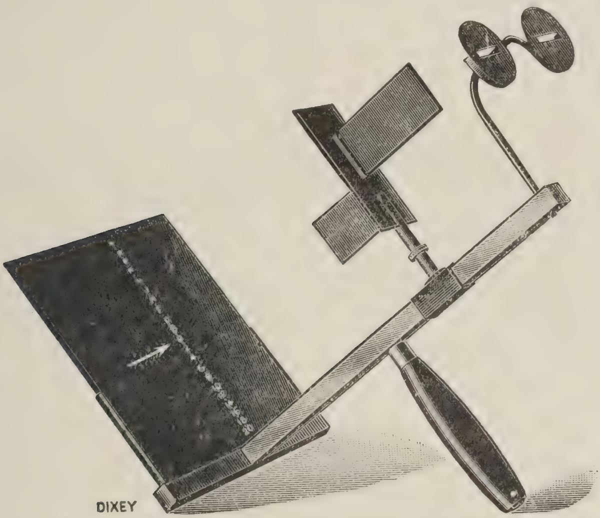


FIG. 179.—This instrument is designed to indicate the muscle balance when subjected to reading conditions. It contains no lenses or prisms and should be held at the usual reading angle. The two visual fields are separated horizontally or vertically as required by wing screens. It measures esophoria and exophoria (with either eye accommodating), hyperphoria, with specially designed charts for each. By using it in conjunction with the trial frame or patient's spectacles any want of co-ordination between accommodation and convergence is easily detected and measured.

The prism verger consists of a frame, in which are mounted two prisms, each of 6° deviation, so that they may simultaneously be rotated in opposite senses by turning a milled head. One of the prisms is permanently attached to the toothed

disc which bears it, but the other can be slipped out of its fitting and reintroduced the reverse way. The object of this is to make the instrument available, not only for horizontal vergence, but also for vertical. A celluloid arc, graduated in degrees, surmounts each prism. The markings on each arc relate, however, not to one prism only, but to the two jointly, one arc being used for horizontal vergence, and the other for vertical vergence.

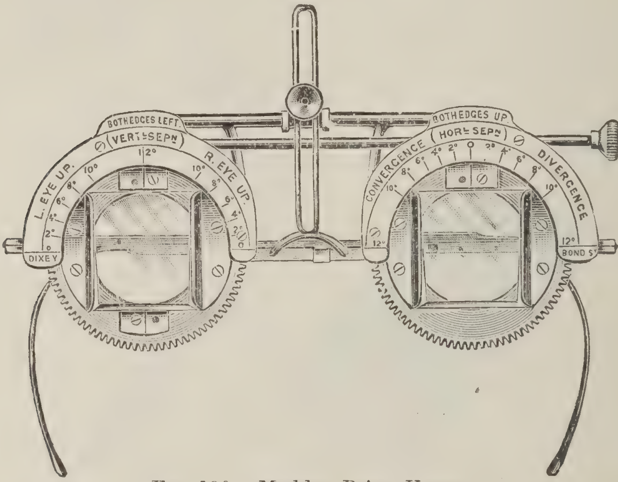


FIG. 180.—Maddox Prism Verger.

To Measure the Horizontal Vergence Power.—Start with both prisms edge up, with their indices pointing to zero; the visual axes experience no lateral deflection. Direct the patient's attention to a distant candle flame, say, at 6 metres, and rotating the milled head counter-clockwise, which causes the edges of the prisms each to rotate outwards, which causes divergence of the visual axes, ask him to notify the first appearance of diplopia. At this point read off the result, which gives the patient's prism diverging power in distant vision.

Next, rotate the milled head in the opposite direction, and in a similar way discover the patient's prism converging power. In making the convergence test the patient should signify the moment the distant object appears double, otherwise the

test becomes one merely of the total convergence rather than for the relative convergence during accommodation for the distance.

To Measure the Vertical Verging Power.—Remove the reversible prism and reintroduce it base upwards and rotate the milled screw until both edges point to the left. Now rotate the milled head counter-clockwise until diplopia is noticed. This causes artificial elevation of the right eye above the left eye. Rotation of the milled head in the opposite direction will cause artificial elevation of the left eye above the right, and in each case the amount of prism diverging power can be read off on the scale.

All tests for heterophoria should be carried out while the patient is wearing the lenses that correct his ametropia, since, as we know, the efforts of accommodation and convergence are so intimately connected that the amount of exophoria or esophoria may be very different if the test is carried out whilst the patient wears his correction on the one hand, and without his correction on the other.

We should first measure the deviation with the glass rod and tangent scale, and decide in the case of hyperphoria by conducting the test with the head first looking straight forward, and then tilted forwards, and then backwards, whether the condition is concomitant or paretic. In exophoria or esophoria the test is repeated with the head turned first to one side and then to the other. The amplitude of convergence should be noted. Then the heterophoria should be measured at 25 cm., the patient, if necessary, wearing his presbyopic correction.

The prism duction should next be measured, chiefly to determine, in esophoria, if it reaches its normal limit of 4°.

Treatment.—*Hyperphoria*, for the reason that we have little power over the vertical deviations of the eye, is not only more likely to lead to symptoms, but also is the latent deviation of the eyes that requires treatment and correction. The discovery of a hyperphoria does not mean that prismatic glasses should necessarily be prescribed. It is only when it gives rise to symptoms that it should be corrected. We must also remember

that sometimes a small error causes considerable discomfort, whereas an error as high as $4^\circ\, d$ may cause no trouble.

If the hyperphoria is *paralytic* the treatment should be in the direction of strengthening the muscle that is weak by exercises, and such general treatment as the case may suggest. The exercises may be carried out by making the weakened muscle exert itself against the action of a weak prism. Thus, suppose there to be $1^\circ\, d$ of right hyperphoria when the eyes are directed to the horizon, we should order a $\frac{1}{2}^\circ\, d$ prism, base up, before the right eye. This glass should only be worn for short periods, say three periods of half an hour each day. Circular prisms, mounted in frames similar in principle to the Maddox prism verger, may be used, each base directed to the right, but one a little upwards, and the other a little downwards, the prism which has its base to the right and slightly upwards being placed before the eye with hyperphoria. With such an apparatus the strength of the prism can be varied on altering the position of the prisms.

In *concomitant* hyperphoria prism exercises do not appear to be of permanent value, and the treatment in contradistinction to exercising prisms is by relieving prisms. Three-quarters of the hyperphoria measured by the distant test should be corrected with prisms evenly distributed before the two eyes, so that in right hyperphoria the right prism should be base down and the left base up. As, usually, only weak prisms are required, the effect may be produced by decentering the lenses worn for any error of refraction.

Insufficiency of Convergence and Horizontal Deviations.—Before speaking of the treatment of horizontal deviations of the eye, it is convenient to describe the condition in which there is a lack of power of convergence, although the matter is not truly a part of heterophoria.

The average amplitude of convergence is usually 16 metre angles, and 20 metre angles are often found. For vision to be used continuously at 25 cm. with comfort, there must be an amplitude of at least 10 metre angles. In some cases, especially in myopia, the absence of accommodative impulse at near

ranges leads to an insufficiency of the power of convergence: in high myopia the great size of the globe also hampers convergence.

When the movements in various directions are examined, no lack of power to move the eye is found, no weakness of the internal rectus muscles. It is only when they are used together so as to bring the visual axes upon a near object, that difficulty is experienced; it gives rise to tiredness of the eyes when reading and is one of the causes of muscular asthenopia. It must also be borne in mind that patients with a broad base line will have a greater difficulty in converging the visual axes than those whose eyes are nearer together, a point of importance in ordering the correcting lenses for near use in cases of presbyopia.

The condition is a functional one, and we must avoid relieving the normal function of the internal rectus muscles by the use of prisms wherever possible, as the condition is likely to increase in severity, so that as time passes stronger and stronger prisms will be required to correct the deficiency.

In young people (who have no presbyopia) the lenses correcting an error of refraction are worn, and exercises performed which will train the conjugate innervations, which may be well compared to the technical finger exercises used by pianists and violinists; these are exercises not so much to strengthen the muscles of the hand and forearm, as muscle relaxation exercises of opposing muscles, leading to skill in the performance of various evolutions. They consist in holding before the eyes in the mid line, a bright object, such as a polished gold bead on a suitable holder and gradually bringing the object nearer and nearer whilst the eyes converge their visual axes so as to maintain single vision. As soon as diplopia is produced the object is returned to its previous distance, at about an arm's length, and the exercise repeated. This should be done a dozen times, three times a day, but fatigue should not be produced. If faithfully performed there is usually a rapid improvement, but the difficulty is often to persuade the patient to perform what are rather dull and uninteresting actions.

In older patients who are presbyopic, great care must be

taken not to prescribe glasses that make the punctum proximum less than 22 cm.; their power of convergence is already reduced, and by having to hold their book unnecessarily near to the eyes, great discomfort is produced. It is a mistake commonly made, and the student should be warned to be careful. Exercises will not be found of value and, therefore, help must be given to produce comfort. If the patient has a wide base line, slightly weaker glasses than those that bring the punctum proximum to 22 cm. should be prescribed for near use, and the patient encouraged to hold his book a little farther from the eyes. The same manœuvre is of value in others with convergence insufficiency. In some, prisms, base in, may be ordered, combined with the reading lenses, care being exercised only to use prisms sufficiently strong to produce comfort.

In the treatment of horizontal deviations we have, in the first instance, to remember that when one eye fixes an object at a distance of 25 cm., the other eye, occluded by a screen, normally deviates outwards 4°, and in many, up to 8°, without causing discomfort, and special care should be taken never to correct horizontal errors unless symptoms call for it.

Horizontal deviations are corrected by prisms placed before the eyes, base in, in the case of exophoria, and base out, in the case of esophoria.

All forms of heterophoria, as we have seen, may be relieved by the use of prisms, but the same effect may be obtained by the suitable decentering of lenses. This will be appreciated when it is remembered that a convex lens is practically two prisms placed base to base, and a concave lens two prisms placed apex to apex (Figs. 30, 31), and also that a convex lens appears to displace objects against the direction in which it is moved, whereas a concave lens appears to displace objects in the same direction as that in which the lens is moved. Consequently to correct a heterophoria we displace convex lenses against the deviation and concave lenses with the deviation discovered by tests.

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